THE

JOURNAL OF GEOLOGY

OCTOBER–NOVEMBER, 1901

INDIVIDUALS OF STRATIGRAPHIC CLASSIFICATION.

INDIVIDUALS TO BE DISTINGUISHED.

SHOULD geologists map the record of physical conditions or the record of biological conditions—rocks or fossils? Both, but with distinction.

When the geologist enters the field to do stratigraphic work, one of the first problems to confront him is where he shall divide the series of rocks he is studying; and often, when reading a paper, we are perplexed to know where these lines have been drawn and what the divisions are intended to represent. This discussion is an effort to arrive at a better understanding of what we classify and what may be mapped.

Since the earliest days of geologic work there has been recognition of different kinds of rocks. For many years geologists compared the various rocks they found, and correlated them from continent to continent on the basis of like physical conditions represented in the similar lithologic characters of the rocks, Identity of physical conditions was interpreted as indicating the same date, but we now know that the physical characteristics of rocks are repeated from time to time, and are diverse in different provinces at the same time, and that therefore they do not afford criteria of contemporaneous deposition. Furthermore, conditions of sedimentation are related to currents, shores, and other moving features; the zones of deposition may migrate

with these features, and an identical sediment accumulate in the migrating zone successively, not simultaneously, over adjacent areas.

After the days of William Smith a second class of divisions arose — divisions based on the fossils which the rocks contain. Fossils were found to occur in certain associations, which were called faunas, and these became the basis of a classification of rocks. On the hypothesis of special creations and destructions each fauna, wherever occurring, represented a certain date, and thus faunas became the significant figures expressing age. But special creation has given way to evolution, and we recognize migration of faunas as a fact. For instance, Walcott has stated that it took a long time for the Olenellus fauna to move round the globe. A greater or less time interval must elapse between the earliest appearance of a fauna at one place and its earliest appearance at another place remote from the first, hence, a fauna does not indicate a precise date in the narrow sense in which it was once taken. Professor H. S. Williams has pointed out that in a wider sense any fauna endures a length of time, from its initial appearance somewhere to its extinction everywhere; and this interval is an episode of evolution which has a fixed place in geologic history. In that sense faunas have definite time values, but the discovery of that value in any case is dependent on refined and extensive paleontologic research.

Accordingly, when studying a stratigraphic series, a geologist may recognize distinctions of lithologic character, variations of faunal content, and succession of physical or faunal changes. The differences enable him to define lithologic individuals, faunal individuals, and time intervals. Though often intimately related, sediments and faunas are by no means necessarily bounded by the same limits in space or in time; they constitute not identical but unlike things. They may migrate together or independently. Either may cease and the other continue. When each of them has been described and discusssed in its local and general relations, the problem of correlation in terms of earth history may be hopefully attacked; but when strata and faunas are treated

under one name, confusion ensues and the conclusion becomes a guess.

It follows that we need to recognize, define, and name three separate things: (1) lithologic individuals; (2) faunal individuals; and (3) time intervals.

LITHOLOGIC INDIVIDUALS.

Definition.—Some twelve years ago there was held a conference of the geologists of the United States Geological Survey, and at that time the basis for the Geologic Atlas of the United States was laid. That foundation was planned upon the simplest lines. It was proposed that the maps should exhibit the distribution of local lithologic individuals.

Referring to the *Tenth Annual Report*, Part I, in the account of that conference we find the following statement (pp. 63–64): "Among the clastic rocks there shall be recognized two classes of divisions, viz., structural divisions and time divisions." Observe that time is set off in contrast to structure, and that structure is not defined by time. Then, defining structural units, the report says (p. 64): "The structural divisions shall be the units of cartography, and shall be designated *formations*. Their discrimination shall be based upon the local sequence of rocks, lines of separation being drawn at points in the stratigraphic column where lithologic characters change." Proceeding to emphasize that, the report further says (p. 64): "Each formation shall contain between its upper and lower limits either rock of uniform character or rock uniformly varied in character." By the latter phrase it was recognized that there might be groups of lithologic individuals which singly could not be mapped because too small—a difficulty which had to be met from the practical side. Furthermore, the report says: "As each lithologic unit is the result of conditions of deposition that were local as well as temporary, it is to be assumed that each formation is limited in horizontal extent; the formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic characters, *aided by its*

stratigraphic association and its contained fossils." (Italics the present writer's.)

Formations and fossils.—That the purpose of the definition is to emphasize lithologic character, and make it the essential of individuality of a formation, is clear, but the habit of classifying roughly by fossils is strong, and the few words here italicized have led many to lose sight of the distinction intended. There is a difference between using fossils as one of several means of identification and employing them as essential characters. In the former case, other characters being the same, the occurrence of a known fossil is an aid, but its non-occurrence sets no limit. In the latter case the range of the characteristic fossils defines the extent of the division. By the one method we may define a lithologic formation according to all its characters. By the second method we limit the lithologic unit by a fauna and a fauna by the lithologic unit, when either may occur beyond the other; and thus, combining two unlike things in one definition, we can recognize neither.

The writer by no means advocates disregard of fossils in the identification of formations. But abundant experience of the ablest stratigraphers shows that classification by faunas requires most refined investigation based upon thorough knowledge of the rocks. To map the formations is a necessary preliminary to determining the faunal units. We should proceed from the simple and obvious to the complex and obscure. We should trace out lithologic individuals, according to their constitution and stratigraphic associations. If these leave us in doubt, fossils may prove valuable ear-marks; but they should not set limits in the discrimination of formations. When the map of formations is made, the way is prepared for the paleontologist to ascertain the number and bounds of the faunal units and to draw the faunal map.

In mapping formations it is convenient to combine them in systems—Cambrian, Cretaceous, Eocene, etc. Fossils are the means of this preliminary rough classification, and the little evidence required is usually obtained in studying the lithology.

But it would be a slur upon paleontology to consider such arrangement final. Even were the dividing planes between great systems fixed, the precise recognition might require detailed investigation of faunas; but in many cases they are not fixed beyond question, either by faunas or by unconformities. Geology has not arrived at a final classification. We need still to accumulate physical and biological facts, to keep them distinct, and to compare them from district to district, and from country to country, before our systems can be said to be established.

The writer is indebted to his colleague, Mr. Whitman Cross, for a case in point—that of the Hermosa, Dolores, and Rico, so-called formations. Quoting from Mr. Cross's statement before the Geological Society of Washington (as revised by him), the case is as follows:

[A diagram exhibited] represented the problems in subdivision of the great series of alternating shales, sandstones, conglomerates, limestones, and strata of intermediate lithologic character represented in the Rico quadrangle, southwestern Colorado. This series of rocks, about 4,500 feet in

Mesozoic	Dolores formation (Triassic)	Red
	Rico formation (Permo Carboniferous)	.....
Paleozoic	Hermosa formation (Upper Carboniferous)	Gray

thickness, extends from the base of the Upper Carboniferous to the top of the Trias. The lower 2,000 feet of strata are characterized by Upper Carboniferous fossils. The intermediate three or four hundred feet by a well-defined Permo-Carboniferous fauna, and a considerable portion of the upper 2,000 feet by Triassic fossils.

Recognizing the importance of the time divisions indicated, the Upper Carboniferous strata have been grouped as the Hermosa formation; the strata bearing the Permo-Carboniferous fossils as the Rico formation; the strata containing Triassic fossils as the Dolores formation. With the Triassic strata are provisionally included at the present time other strata not known to be fossiliferous. The upper limit of the Dolores is a definite lithologic and structural horizon. The lower limit cannot be determined upon lithologic grounds alone. *As a line must be drawn on arbitrary grounds*, the Dolores complex has been extended below to the uppermost stratum containing

Permo-Carboniferous fauna. This alternation of strata of different lithologic character can be subdivided in great detail when the exigencies of mapping require it. *The important lines limiting the Rico formation above and below cannot be drawn upon lithologic grounds.* If lithologic character alone is relied upon for the subdivision of this great complex embracing strata belonging partly to the Paleozoic and partly to the Mesozoic, the formation units would be of relatively minor importance, and the great historical subdivisions would not be expressed. The criterion of color applied to this complex groups the Permo-Carboniferous with the Trias. This has been done in previous general discussions of this complex in this region. In fact, the Permo-Carboniferous beds should be grouped with the Carboniferous if the larger elements of time division are to receive recognition upon the geologic map of the Rico quadrangle. (Italics the present writer's.)

There are two questions involved: First, what Mr. Cross's map expresses; second, what it should express. The Hermosa, Rico, and Dolores are clearly not formations in the sense defined in the *Tenth Annual Report*, for lithologic continuity is divided at the top and bottom of the Rico on the basis of contained fossils. They are intended to be faunal divisions, but their limits are very ill defined, since fossils are commonly so few in the Red Beds that the finding of them higher or lower in the series is a matter of accidental discovery rather than of occurrence. The map appears, then, to express indefinitely the arbitrary application of a time scale (Paleozoic, Mesozoic or Carboniferous, Permo-Carboniferous, Triassic) to a series which is capable of division into lithologic individuals. Were it so divided it would yield a record of physical conditions, a record which is now obscured by this classification.

It is an important fact that conditions of erosion and deposition were continuously favorable to the accumulation of red sediments while biologic migration or evolution modified the organisms present from Paleozoic to Mesozoic types. But in discussing the formations their continuity is the essential, just as in describing the faunas their discontinuity would be. To impose the division of the latter upon the lithologic individual is misleading, and to call the faunal units "formations" in a publication for which that term has been accurately defined is a misuse of the word.

A very similar case is that of the Shenandoah limestone, which carries Cambrian fossils in its lower portion and Calciferous fossils near the top. But, though it thus corresponds to parts of two great periods, as we usually classify geologic time, it is mapped as one formation because it is a lithologic unit.

Formation names. — "The formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic characters, aided by its stratigraphic association and contained fossils." Following this rule (*Tenth Annual Report*, Part I, p. 64), various cases may arise, some of which are illustrated in the accompanying diagrams.

Figure 1 shows the *m* shale passing into a limestone which retains identical stratigraphic associations. Being exactly continuous stratigraphic units, they should retain the same geographic name on grounds of convenience and simplicity.

Figure 2 shows the *m* shale grading into a limestone with prolonged overlap, so that the two rocks must be discriminated in one area. Not only are they lithologically different but they have different stratigraphic associations, and they should receive distinct geographic names: *m* shale and *n* limestone.

Figure 3 shows the *m* shale continuing as an individual with reduced thickness into new stratigraphic associations. Individuality is not dependent on thickness nor on stratigraphic association only; it is determined by continuity, and the formation may retain its name, *m* shale. But the group *pms* cannot then be called the *m* group, because *m* would have two meanings, one for a simple part, and one for a complex whole.

Figure 4 shows the *m* shale replaced by five formations, two of which, *B* and *D*, are shales like it. Individuality is here lost in multiplicity. Neither *B* nor *D* can be distinguished as representing *m*, which must, accordinly, give way where they divide into two. The complex *ABCDE* may be called the *m* group, since it has equivalent stratigraphic associations with *m*.

Figures 5 and 6 illustrate the occurrence and naming of local lenses in a formation where such divisions are not of sufficient

extent to justify a distinct series of names for the lens and the parts of the formation above and below it. One lens may receive the formation name, but two or more must be named distinctly.

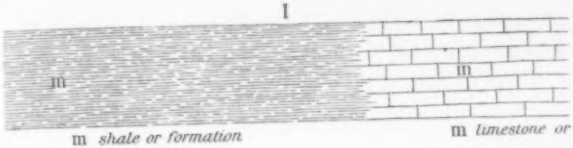
Figure 7 presents the case of a formation which is a least practicable lithologic individual for mapping, but which includes fractional parts that are important in discussion. The fractional character of the parts may be indicated by calling them members, each member being given a distinctive geographic name.

Lithologic individual and thickness.—Thickness is not an essential character of a lithologic individual. Layers, strata, beds, and their complexes vary so generally in this respect that individuality based upon constancy thereof must be lost in a short distance. And if thickness be not constant for any one individual, still less can volume be considered an element of the definition of formations in general. Lithologic individuality knows no such limits. Continuity of rock character is the essential core of the definition, and this may extend through a hundred or a thousand feet or more or less.

The writer has avoided the use of the phrase "lithologic unit," because discussion developed the fact that, in the minds of some, unit means a definite quantity, and these persons think that a thick formation should be a group or series, because of its magnitude. Not volume, but uniformity of constitution, defines a lithologic individual or " formation."

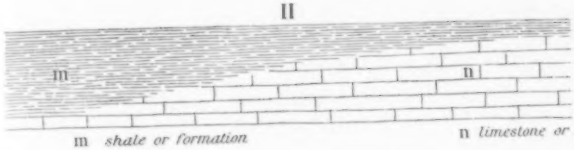
Lithologic individual and time.—Thickness of strata, at right angles to bedding, is considered a measure of the epoch of deposition, due account being taken of the estimated rate. Thus for that particular place the lithologic unit is significant of definite lapse of time. It bears, however, no mark of date. If we trace the formation a hundred or a thousand miles, and again measure its thickness, another determination of an epoch is obtained, again without date. Are the epochs identical ? The common assumption is that they are, and one reads of the epoch of the Dakota formation without reference to locality. Thus used, the phrase should mean all the time during which the Dakota sandstone was spread from its eastern to its western

I



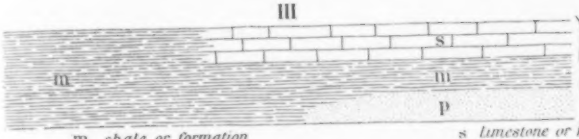
m *shale or formation* m *limestone or formation*

II



m *shale or formation* n *limestone or formation*

III

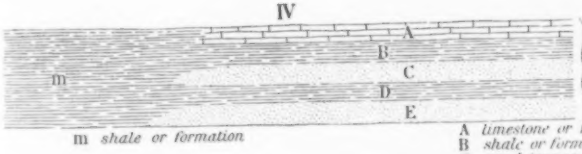


c group

m *shale or formation*

s *limestone or formation*
m *shale or formation*
p *sandstone or formation*

IV



m *group*

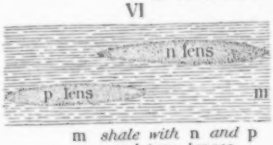
m *shale or formation*

A *limestone or formation*
B *shale or formation*
C *sandstone or formation*
D *shale or formation*
E *sandstone or formation*

V

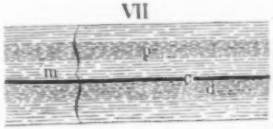
m *shale or formation and* m *lense*

VI



m *shale with* n *and* p *sandstone lenses*

VII



m *shale or formation including* p *fire clay member,* c *coal member, and* d *fire clay member*

limit. Since that transgression took a long time, the eastern Dakota sandstone is older than the western; and as the advancing zone of sand accumulation, following the shore, was in turn followed by a zone of shale deposit, the eastern sands were being buried under Benton shale while the western sands gathered. When the transgression ceased and Niobrara chalk was laid down, the conditions were more nearly uniform throughout the sea. Niobrara then probably marks approximately one and the same epoch throughout its extent. Benton may do so in less exact degree; and Dakota corresponds at an eastern point to the beginning, at a western to the closing, of the cycle of deposits.

It is convenient to conceive the time scale as marked by horizontal lines. On such a scale the Dakota formation would be represented by a diagonal line, and the Niobrara by a nearly horizontal line.

The writer does not put these ideas forward as new; but in defining a formation it is important to clear away certain misleading conceptions that appear in the literature and in discussion of the points at issue. Only at a particular place does a formation belong to a definite age: when traced to another locality it may be older or younger.

FAUNAL UNITS.

Classification by faunas.— The term faunal unit or individual is here used as a parallel to lithologic individual, to designate a set of strata characterized by a common fauna. The writer does not undertake to say whether a fauna should be defined by varieties, species, or genera; by recognition of one or many associated organisms. It may be granted that a fauna is something which each working paleontologist will define for himself within certain broad limits, just as lithologic character is something which each stratigrapher defines for himself within certain limits. But classification of strata by faunas is a different thing from classification by formations.

Professor Williams, in 1897, published a paper on dual

nomenclature, in which he clearly stated the distinction which the present writer would now emphasize between a lithologic individual and a faunal unit.

Following the language in which a formation is defined in the *Tenth Annual Report*, a faunal unit may be defined as follows:

LITHOLOGIC INDIVIDUAL.	FAUNAL UNIT.
"The structural divisions shall be units of cartography, and shall be designated *formations*. Their discrimination shall be based upon the local sequence of rocks, lines of separation being drawn at those points in the stratigraphic column where lithologic characters change."	The faunal units shall be units of correlation, and shall be designated stages.[1] Their discrimination shall be based upon their fossil content, lines of separation being determined at those points in the stratigraphic column where faunas change.

Pursuing the description of a faunal unit, or stage, we may say further: As a faunal unit is characterized by the life which it contains, and as organisms are migratory, it is not to be assumed that a stage is limited horizontally. It may be recognized in diverse provinces or continents, and therefore the name which a faunal unit receives should not be a local name, but should be applied wherever that unit is recognized.

Distinctions between formation and stage.— A formation is a set of strata characterized by and limited to uniform constitution. A stage is a set of strata containing and limited to a certain fauna.

Lithologic constitution results from conditions which are local and temporary, and which, though migratory, are rarely more than provincial in extent. A fauna, though evolved in adaptation to local conditions, may be capable of world-wide migration. A formation, therefore, is geographically limited; a fauna is not, necessarily.

Physical conditions which determine rock constitution are recurrent and repeat the deposition of similar sediments. But organisms, once extinct, do not reappear. Accordingly, a

[1] The term *stage* is here used provisionally, to afford a word for the purposes of this discussion only.

formation may belong to any geologic age; a fauna belongs only to that age in which it was evolved and died out.

A principal object in studying formations is to read the physical history of the earth, but the principal object of investigating fossils is to get at the life history. Each is an essential aid to the other, and the time relations of fossils are fundamental. But the two lines of inquiry should not be confused. They are confused when we call a stage a formation, or *vice versa*, or place the limitations of the one upon the other.

STEPS IN GEOLOGIC SCIENCE.

The question with which this article opens may now be given a fuller answer. The first step in the geologic study of any locality is to ascertain the relations of the rock masses, and those relations are most happily expressed in a map which exhibits the distribution of formations. This map illustrates local facts. It can be complete in itself, even though no connection is established between the facts of that particular district and those of the world at large, but if it be a correct map it will fit into the general record when the connections are traced.

The second step in geologic investigation is the detailed study of faunas and their distribution in stages. To this second step the first is an essential, as a good topographic map is to both. Through close analysis of the faunas and comparative study of their distribution, the data may be gathered for a map of the stages represented in the district. This map of stages may in some cases resemble closely that of the formations, but in others there will be marked differences.

With the development of maps showing the distribution of stages we may arrive at correlation of events, and thus be able to compare physical conditions the world over, fitting into its place with some degree of exactness the record of the formations for any locality. Thus correlation is the third step, a step which may be facilitated through other lines of research, but which is fundamental in broad studies of the earth's history.

With a better knowledge of the physical geography of the globe at successive epochs we may more hopefully attack the great problems of mountain growth, continental development, and earth dynamics. But our first work is to map the lithologic individuals, while our associates, the paleontologists, distinguish the faunal units of stratigraphy.

BAILEY WILLIS.

THE DISCRIMINATION OF TIME-VALUES IN GEOLOGY.

THE imperfection of the present systems of classification and correlation of sedimentary rocks concerns more directly the interpretation of the facts than the facts themselves.

The work of the geologists of the United States in mapping and recording the stratigraphic sequence of formations was never more exact and comprehensive. The paleontologist was never more particular in his records of the faunal contents of each formation and fossiliferous zone, and his comparisons were never more full and precise. But the extension of knowledge over vast territory has brought to light hundreds and thousands of outcrops of the same formations, showing a diversity of faunal composition which cannot be translated entirely into difference in geologic age.

So long as surveys were confined to local areas separated by spaces across which the continuity of formations could not be traced, it was practicable to use a system of nomenclature and classification in which lithologic formations and their stratigraphic succession were chiefly considered. When, however, the intervals between local areas were filled up and it was necessary to correlate geological sections in which the formational divisions are in part or wholly dissimilar, the duality of the lithologic and biologic facts become apparent. These two sets of facts are entirely different in nature and in origin, and for their scientific discrimination duality of nomenclature is essential.

The confusion of these two kinds of evidence was natural, and has been perpetuated by the common practice of adopting the lithologic formation as the unit of classification, making the time divisions to apply strictly to the formations instead of to the faunas and floras, by which alone the chronologic epochs in which they were formed can be discriminated. This confusion

it seen in the discussion of classification and nomenclature in the *Tenth Annual Report* of the United States Geological Survey, and in the legends of the folio maps. For instance, take the Sewanee Folio, Tennessee: The legend is as follows, viz.:

Walden sandstone Lookout sandstone Bangor limestone Fort Payne chert	Carboniferous.
Chattanooga black shale	Devonian.
Rockwood formation Chickamauga limestone Knox dolomite	Silurian.

According to the rules in the *Tenth Annual Report*, the first series of names are "*structural divisions* . . . . units of cartography, and shall be designated *formations*" (p. 64).

The second series of names are "*time divisions* . . . . defined primarily by paleontology and secondarily by structure, and they shall be called *periods*" (p. 65).

Although everybody understands what is meant by the classification in the legend, the principle described in the rules is wrong in that the legend on the map refers to a classification of rocks: and the real fact in the case is that in the Sewanee quadrangle the Walden, Lookout, Bangor and Fort Payne formations together constitute the Carboniferous *system*, and the map makes no record of periods of time but only of formations of rocks. The Devonian system of that quadrangle consists of the one Chattanooga formation; and the Rockwood, Chickamauga, and Knox formations are the only representatives of the Silurian system recognized on the sheet.

The European nomenclature avoids this confusion by recognizing a set of stratigraphic names and their categories; with a corresponding set of categories for the chronologic classification—the names of the divisions being the same in both the stratigraphic and chronologic scales. Instead of referring all stratigraphic divisions to one category (the formation), different

categories are used for formations of different relative size; making the list of names to be group, system, series, stage, as adopted by the international Congress. Each of these stratigraphic divisions has its corresponding chronologic category, viz., era, period, epoch, age. The European has no difficulty in expressing on the map, or in discussing, either the time or the structural relations of the formation. On the map, the Walden, Lookout, Bangor, and Fort Payne would be to him four series, together constituting the Carboniferous system. By placing the Chattanooga in the category of series he at once would indicate that he does not regard the formation as necessarily representing the whole Devonian system. On the other hand, when he speaks of the Carboniferous period he is not discussing any local set of formations but the total period of time in which lived a definite set of plants and animals, only a few of which are discovered in any one local formation. There can be no question that the systems of the European geology can be recognized in this country *only* by the fossils—but that does not change them from formational aggregates into time divisions.

The implication in the *Tenth Annual Report* that the divisions which are discriminated by fossils must be chronologic, and not structural, suggests the way in which our usage may be improved; but the fallacy of the principle is seen by noticing that the smaller formations (the series and ètages of the international nomenclature), are to be discriminated by their fossil contents as well as the larger ones (the systems). If discrimination "primarily by fossils" were to be the test as to whether the division were structural or chronologic then formations would become chronologic divisions in every newly surveyed area in which actual lithologic continuity could not be traced to some standard outcrop.

These two sets of facts (structural and paleontological) both have to do with the classification of formations on a time basis; and those who are accustomed to frame their conceptions of geological time on the basis of one set of facts, find difficulty in even conceiving that there is any other basis.

TIME VALUES OF FORMATIONS.

The regular sequence of stratified sediments forms a natural geological column, which, in any particular section of the earth's crust, is so conspicuously subdivided by lithologic differences in kind of sediments that the divisions form the most satisfactory kind of natural time division for geological classification.

These natural, lithologic divisions of the crust of the earth are technically called formations in the nomenclature of the United States Geological Survey. And in any standard section, such as that of New York state, the order, composition and thickness of the several formations is exactly known; and for that section, too, the fossils of each separate formation are known accurately and in large numbers. Geologists have been accustomed to use such a local column of known geological formations as a *standard time scale;* and as examination has extended to sections of the crust in other parts of the continent, the classification and correlation of the other columns have been made to correspond, by correlation, with such a standard column of formations. Two methods have been used in establishing the correlation: (1) by tracing continuity in the lithologic formation; and (2) by recognition of identity of the fossil species contained in the formations. Both of these methods have rested on an assumed interpretation of the facts, the correctness of which may be questioned quite independently of the established fact of continuity or of identity.

The assumptions on which these interpretations rest are that correlations of time relations can be established in the first case by *continuity of lithologic formation*, and in the second case by *identity of fossils*. In regard to the first case, it would be incorrect to say that the assumption is entirely false, for in some cases, and to a limited extent, lithologic continuity of a formation is undoubtedly synonymous with sameness of the period of the sedimentation represented by the formation. But the facts are abundant, and well known to all field geologists, to prove that formational continuity is not co-ordinate with lithologic uniformity; and since our standard definition of a formation

(*Tenth Annual Report*, United States Geological Survey) is based upon its lithologic uniformity, it is certain that in all cases in which the lithologic changes affect the upper or lower limits of a formation (which is expressed by thinning or thickening of the formation) there must be discordance between the formational continuity and the time represented by it. It requires but a moment's reflection, further, to show that two sections in different regions may, on other evidence, be known to represent the same interval of time but present no similarity lithologically; this can receive only the one interpretation that formational discontinuity does represent time uniformity, which is the converse of the original assumption.

In other words, while it is practicable in some cases to assume that formations which are clearly continuous may be deposited during the same period of time, it is clear that lithologic uniformity (by which the continuity of the formation is recognized) is not a safe guide in making chronologic correlations, however much value may be placed upon the lithologic divisions of a standard geologic section, as natural divisions of a geologic column made on a time basis. The tracing of time equivalences by formational continuity is unsatisfactory, not because of any failure on the part of a formation, as a lithologic unit, to represent a definite period of geologic time, but because the time relations of the formation are not expressed by any of the lithologic characters by which one formation is distinguished from another. The confusion the geologist is apt to fall into in discussing this point may be illustrated by the measurement of the altitude of a rock outcropping on a mountain side. The base of the Olean conglomerate, for instance, as it appears at Olean Rock City may represent exactly the altitude of 2,340 feet above the level of the sea (*McKean County Report, Second Pennsylvania Geological Survey*, R. 59), but its altitude above the sea has no relationship whatever to any of its lithological peculiarities. In forming an altitude scale, it is in the region a conspicuous mark for the altitude at which it lies, and if its dip be considered, the continuity of the

conglomerate may be relied upon for estimates of approximate altitude. Nevertheless, in itself the formation possesses no altitude value, it is only a conspicuous stratum in the region where it appears, that now lies at a definite elevation above the sea—the amount of the elevation must be determined by other means. It may indicate an altitude already determined, but it has no intrinsic altitude value, and is not a measure of altitude.

In similar manner we may say that the geologic formation, as a lithologic unit, was formed at some definite epoch of geologic time which may be approximately measured by other means; but the amount of time from any datum point to the time when it was formed is not in any degree indicated by the lithologic or structural characters of the formations; and in this sense a formation may be strictly said to possess no intrinsic time value, but to require the "paleontologic evidence" to prove to what "period" of time it belongs. This conclusion might almost be drawn from the statements regarding periods in the *Tenth Annual Report* (p. 65).

It is, however, not necessary to remind geologists that fossils possess a value as means of determining the time relations of formations. But this time value of fossils will be better appreciated if attention be given to the nature of the evidence furnished by fossils regarding the period of time in which they lived.

TIME VALUE OF FOSSILS.

Fossils derive their time-value from the fact that the morphologic characters presented by them are temporary in nature. The form of a trilobite, expressed in its various morphologic characters, was constructed by organisms at a definite period of time in the history of the earth; so that the presence of a fossil trilobite imbedded in a rock formation is direct evidence of the geologic age in which alone the trilobite lived. Hence it is that for the whole surface of the earth fossils become marks of the time divisions and the means of correlating formations on a time-basis; this is the second method of correlation referred to above. Identity of fossils is direct evidence of sameness of time. But

in applying such a statement much confusion and imperfect correlation has arisen by failure to recognize *wherein consists* the time-value of the fossil.

Identity of fossils may be wrongly interpreted — a trilobite is a trilobite, it is true, but one trilobite is a *Paradoxides* and another is *Phacops;* and the one indicates an early period of Paleozoic time, while the latter indicates a much later period. Then, again, *Phacops cristata* appeared in the early part of the life history of the genus *Phacops*, while *Phacops rana* is a later species of the same genus. Thus it is evident that in speaking of *identity* of fossils one may have in mind the same *class*, the same *order*, or the same *family*, *genus*, or *species;* and the time value will differ according to the category of zoölogical classification to which the identity applies. The time represented by the morphological character of the genus *Paradoxides* is much shorter in length than that represented by the sub-class Trilobita; and the period of time represented by the characters of the genus *Paradoxides* is diverse from that represented by the genus *Phacops*. So in regard to all kinds of organisms represented by fossils: the morphological characters expressive of the more comprehensive zoölogical divisions are of greater antiquity than those of less comprehensive divisions. The time-value of a class character is, in most cases, as long as all the recorded time of stratified rocks; while the time-value of a species is often not over a tenth of that length.

In order to discuss these time relations it becomes necessary to make scientific discrimination of the characters of organisms in their time relations. First of all, what is it about the organism which is directly co-ordinate with time? An answer to this question will be reached by considering the fundamental characteristic of organisms — their *growth*. The form possessed by any organism living is expressed only as the individual grows or develops from an embryonic or *formless* state. The form is *acquired* by each individual organism; always by individual development requiring duration of time. This time is the living period of the individual. If every individual developed some

morphologic peculiarity by which it could be distinguished, each such individual would represent a definite point of time, and the succession of individuals thus distinguished would express the history of the world in terms of the life periods of the successive individuals. Practically it is impossible so to distinguish the characters of individuals that they can serve as time indicators.

The naturalist does, however, recognize characters of sufficient distinctness to differentiate one species from another. Specific characters, like individual characters, have been acquired gradually as generation has succeeded generation in ordinary reproduction. The process of acquiring specific characters is called evolution; and specific evolution takes longer time than individual development. The length of time during which in any particular race generation continues without appreciable disturbance of the specific characters of the offspring, varies in different lines of descent, and specific characters are more readily distinguished in one case than in another. But in all cases the continuity of the specific characters without special change represents a considerable period of geological time, and this length of time is measured by the presence in the formations of the same species of fossils. The period of the continuance of the same species is therefore a definite length of time for each species, since each species began at some definite time, and (unless now living) became extinct at a later definite point of time. This definiteness of the life-period of a species is independent of our present knowledge either of its measure in years, or of the thickness or stratigraphic position of the formation in which the fossils are preserved.

Having noted that the morphologic characters of organisms are temporary in nature, we may further observe that this temporary quality has to do with the vitality of the organism in a measurable way. As in the case of two living organisms we consider the vigor of that one to be the greater, which, under similar circumstances, lives the longer; so, in general, the length of endurance of a species may be taken as the measure of some

kind of enduring power which inheres in the race itself. This enduring power of organisms, expressed by the repetition of like characters in successive fossil forms, is the time quality which has already been used by geologists in making correlation of formations by fossils, and to which we must look for the making of a scientific time-scale.

In order to isolate this time quality I have proposed to speak of it as the *bionic* quality or value of the organism. *The bionic quality of an organism may, then, be defined as its quality of continuing, and repeating in successive generations, the same morphologic characters.* In the case of the unit individual, it is the *continuing* of the characters, since biologically the use of parts wastes them; and only as they are renovated may they be said to continue; the active organs are here alone under consideration, for the inactive hard parts are biologically dead parts whose endurance is dependent only on absence of agencies of destruction. If, now, we can discover some way of observing, recording, and measuring the bionic values of fossils, we will be furnished with a means of constructing a geological time-scale on a separate (not to say independent) basis from the supposed time-scale represented by the geologic column of successive formations.

In the development of such a time-scale the first point to notice is that *the characters of organisms differ in their bionic value in direct proportion to their taxonomic rank.* Thus, as we have seen in the case of the Trilobites, the characters which have ordinal or sub-class rank have persisted in the history of organisms vastly longer than the characters of generic value; and these are of greater bionic value than specific characters.

In discriminating periods in geological time we may look first to the well-known categories of zoölogy and botany, as a basis of determination of the order of rank in the time divisions, viz., the time of endurance of a specific character (or, concretely, the length of time represented by the presence of the same species in successive strata of the rocks) is of subordinate rank to the time of endurance of a generic character. And if we should adopt the name *chron* to apply to geological time-units in general,

and *biochron* to the units whose measure is the endurance of organic characters, we have a means of constructing a system of nomenclature which will express what is now known of geological time relations, and (more important still), which will serve as an aid in accumulating the necessary statistics to perfect the geological time-scale.

ORDER OF MAGNITUDE OF BIONIC UNITS.

In expanding this system of nomenclature the following table will indicate the principle upon which the fundamental units of time value will be discriminated and named. The time unit of lowest rank will be based upon the life endurance of an individual organism; the amount of organic vigor expressed by the preservation of the individual life constitutes a bionic unit of simplest or lowest rank; the individual, therefore, is an organic unit of monobionic rank. How many individual lives are possible in the life-history of a species we at present do not know, but we do know that the bionic value of the species (or, strictly speaking, of specific characters) is of an entirely higher order than that of the individual. To be more concrete the individual, the species, the genus, etc., constitute organic units of consecutively higher and higher order of bionic magnitude, which statement may be tabulated in the following way:

THE BIONIC VALUES OF THE SEVERAL CATEGORIES OF CLASSIFICATION OF ORGANISMS.

Individual	a monobionic unit.
Species	a diobionic unit.
Genus	a tribionic unit.
Family	a tetrabionic unit,
Order	a pentabionic unit.
Class	a sexbionic unit.

In the table the bionic order of magnitude is expressed by the prefix *mono-*, *di-*, *tri-*, etc.; thus the dibionic unit is an abstract mode of naming the order of magnitude of the organic force expressed in preserving, by generation, the specific characters of an organism. Comparing this with the force which preserves in like manner generic characters, the former is seen to be of second

order of magnitude, while the latter is of tertiary order of magnitude. So far the magnitudes are relative, and they become concrete only when the bionic value of the characters of some particular species or genus is considered.

Paleontologists are familiar with the very long range of the species *Atrypa reticularis; Rhynchonella cuboides*, on the other hand, has a very short range. In the nomenclature proposed (so long as both are considered to be species), the fact would be expressed by saying that the *Atrypa reticularis* biochron is longer than the *Rhynchonella cuboides* biochron. Nevertheless, in the familiar categories used by the zoölogist and botanist is found a means of expressing definiteness in, at least, the order of magnitude of biochrons; whereas there is no way of distinguishing the order of magnitude of geochrons, except in feet thickness. In the case of the biochron it is only necessary to indicate the name of the species or genus in order to fix a definite value to the biochron. Such values are already definitely expressed when we speak of the "reptilian age," the "age of fishes," the "olenellus zone." The definiteness is indicated by the name of the particular group of organisms made use of, or adopted as the measure of the biochron.

THE DUAL NOMENCLATURE.

In proposing a dual nomenclature it is essential to indicate this basis of measurement of the chron, and to distinguish the *geochron* (expressed in terms of feet thickness of stratified sediments of uniform lithologic constitution) from the *biochron* (expressed in terms of presence in the sediments of fossils of the same species, genus, or family).

Thus the time value of the Hamilton formation would be spoken of as the *Hamilton geochron;* while the time value of the species *Tropidoleptus carinatus* would be the *Tropidoleptus biochron*. The same kind of difference in values is observed to pertain to both biochrons and geochrons. As it is impossible to fix any standard length for the endurance of a species, so it is impossible to fix any standard of thickness for geological formations; they may vary from a few inches to many hundreds of feet in thickness.

Since the thickness, as well as the kind of sediment, varies with the geographical locality, the association of a geographical name with the lithologic character of the formation becomes a definite and precise mode of identifying a formation; so that the name "Medina sandstone" becomes a definite formation name, the characteristics of which may be observed, and their definition fully elaborated at Medina, where the formation appears with its typical characters. Its place in a geological column, its thickness, and its composition, are all made definite by the name *Medina;* any sandstone outcropping elsewhere can be classed as "Medina sandstone" only by possessing the characters considered to be essential to formational continuity and integrity. Of course one of those characters may be theoretically defined as the geologic time of its deposition; this may be indicated by the contained fossils. But formational continuity and identity may be established in the case of non-identity of fossils, and in one section the fossils may rise to a higher stratigraphic plane than in another; so that actual *formational continuity may disagree with the evidence of duration presented by the fossil species.* This fact is illustrated in the case of the Catskill formation, which is known to occupy a stratigraphic position in eastern New York and Pennsylvania continuous with rocks further west, possessing both different lithologic characters and containing fossils regarded as characteristic of the Chemung formation. Such facts find easy expression when the nomenclature is furnished us by which to separate a geochron from a biochron. The *Spirifer disjunctus* biochron is a different thing from the Chemung geochron. In defining the Chemung formation it has become necessary to distinguish it from the formation following it. This following formation in many sections in New York and Pennsylvania is a red sandstone and shale lacking the marine fossils, sometimes holding fish of possibly marine, but probably brackish-water habitat. For purposes of mapping and classification, the Chemung formation is succeeded by the Catskill formation; but the evidence is conclusive that the time of deposition of the red sediments of the Catskill formation of eastern

New York was in large measure synchronous with the sedimentation of gray rocks with abundant marine fossils, including *Spirifer disjunctus*, in western New York and Pennsylvania.

If the endurance of the *Spirifer disjunctus* fauna be made the mark of the *Spirifer disjunctus* biochron, it becomes quite possible to state and discuss the facts as they are, and to understand the natural explanation of the facts as a gradual transgression of the shore from which the red sediments were deposited westward with the progress of time. The geochron of red beds began earlier in the scale of biochrons, and as we expand the idea we will discover that it is also earlier in actual geological time, and that the biochron is the measure upon which we must depend in constructing the standard geological time-scale.

THE CONSTRUCTION OF A BIONIC TIME SCALE.

The next question arises, how shall this time-scale be constructed? First, it must be constructed, primarily, on the basis of the bionic values of the fossils. Secondly, the names of the time divisions must be distinct from those used in designating the formational divisions of the rocks. Thirdly, biological names should be chosen for the divisions, and so far as practicable, some abundant or characteristic fossil should furnish the name; as in naming formations the locality in which the formation appears in full force and with full characteristics is used. Fourthly, it cannot be expected that the divisions of an accurate time-scale, based upon many different sources of measurement of the time intervals, will present a continuous series without breaks and without overlapping of the divisions. If a single means of measuring the lapse of time were used, such breaks and lapping might be avoided; only in case the beginning of one species or fauna was everywhere dependent upon the cessation of the preceding one, could the scale be made without liability of failure to meet at the limits of the time intervals indicated. Fifthly, the classification and definition of geological formations should be made, so far as practicable, independent of the fossils or the time relations indicated by

them; and the fossils should be used (as now their use is scientifically most valuable) in establishing correlations, not in furnishing definitions. Sixthly, the selection of the grander time divisions should be made to conform, so far as found practicable, with the standard divisions of the formation scale; but their discrimination should be based strictly upon fossil evidence and not upon the lithologic or stratigraphic characters of formations. Seventhly, in forming the time-scale the continuance of the fauna in its integrity, as marked by the dominance of its characteristic species, will constitute a more satisfactory basis of discrimination than the species alone. Slight differences in the aggregate of species found in the successive strata of rocks is quite consistent with the continuance of the fauna in its integrity, and to distinguish the *fauna* as a whole from its local and temporary expression the latter may appropriately be called a *faunule*.

In constructing a time-scale on the basis of the bionic values of fossils, it is practicable to give to the categories now in use greater precision and scientific definition. If geologists chose to adopt the following terms in the restricted sense designated, such a set of terms would prove of great value.

TERMS OF THE BIONIC TIME SCALE.

Chron.—An indefinite division of geological time.

Geochron.—The time equivalent of a formation.

Biochron.—The time equivalent of a fauna or flora.

Hemera.—The technical name for a monobiochron, indicated by the preservation of the individual characteristics of all the species of a local faunule, as shown by the association in the rocks of the same species, in the same relative abundance, size, and vigor. An example is the hemera of *Rhynchonella* (*Hypothyris*) *cuboides*.

Epoch.—The name of a dibiochron, indicating the time equivalent of the endurance of a particular species and of the integrity of the fauna of which it is the dominant characteristic. An example is the *Tropidoleptus carinatus* epoch, which corresponds closely to the limits of the Hamilton formation of eastern New York.

Period.—May be defined as a tribiochron. This is the time equivalent of the continuance of a *genus*. An example is the *Paradoxides period*, which corresponds to the Acadian formation of the Cambrian system.

Era.— May be used to indicate a tetrabiochron; and *Olenide era* would indicate the life range of the family *Olenidae*, corresponding in length, approximately, to the geochron of the Cambrian system, though not strictly so.

Eon.— May stand as the name for a pentabiochron; an example of which is the *Trilobite eon*, the time equivalent of the continuance of the order, or sub-class, *Trilobita*, which closely approximates the length of the Paleozoic geochron.

CLASSIFICATION AND NOMENCLATURE OF THE TRILOBITE EON (PALEOZOIC) CONSTRUCTED ON THE BASIS OF THE BIONIC VALUES OF FOSSILS.

Eon	Periods	Epochs	Formational Equivalents (Approximate)
Trilobiteon	7. Phillipsian	Cameratus	Coal measures.
		Increbescens	Kaskaskia, St. Louis.
		Logani	Keokuk, Burlington.
		Marionensis	Kinderhook.
	6. Phacopsian	Disjunctus	Chemung.
		Mucronatus	Hamilton.
		Acuminatus	Corniferous.
		Arenosus	Oriskany.
		Macropleurus	Lower Helderberg.
	5. Calymenean	Vanuxemi	Waterlime, etc.
		Radiatus	Niagara, etc.
	4. Asaphian	?	Ordovician.
	3. Olenian	?	Cambrian.
	2. Paradoxidean		
	1. Olenellian		

Applying the principles set forth in this paper, a tentative table may be constructed which will express concretely what is meant by a biochronic classification and nomenclature. In this table the attempt is made to find names of genera of Trilobites for the periods of that eon in which Trilobites constitute a characteristic feature. The genera chosen actually do lap over each other in several places, but it is doubtful if any genera could be chosen which, if they did not lap over in their chronologic range, would leave actual gaps not represented in any division of the scale. The genus *Spirifer* is selected in the upper

divisions of the scale, as furnishing a convenient set of diagnostic species; they, too, do not in every case avoid lapping, a difficulty which it has already been said is unavoidable when the means of measurement are multiple and not mutually exclusive. The foregoing table is offered, then, as a means of illustrating the proposed plan.

HENRY SHALER WILLIAMS.

NEW HAVEN, CONN.

VARIATIONS OF TEXTURE IN CERTAIN TERTIARY IGNEOUS ROCKS OF THE GREAT BASIN.[1]

INTRODUCTION.

During the field work of the writer in the Great Basin, in 1899, he found in a number of localities, chiefly near the edge of the Sierras, cases of what seemed at first extraordinary transitions or intimate alternations of texture in the Tertiary igneous rocks, which are for the most part extrusive. Microscopic and comparative examination in the office corroborated the field conclusions and showed also that the transitions were not as abrupt as they seemed at first, but were more gradual; and the study of the conditions of crystallization which may be inferred from the structure of the different varieties shows that similar conditions must exist in many other places and similar transitions may be looked for. It is true that there are in that portion of the Great Basin especially under consideration (namely, the district lying within fifty miles of Carson) exceptionally favorable circumstances for the exposure of both the surface portions and the originally deeply buried portions of lavas. The region is an arid one, and therefore the general erosion is slight; nevertheless, waters derived from the moister Sierras reach out into this region in the form of streams, and have accomplished much special or basal[2] erosion. There are also a number of lakes, which in former times were much more extensive, and probably existed in one stage or another since early Tertiary times; and the basal erosion of these lakes has proba bly been considerable.

Some of the special localities where the observations were made will now be described in detail.

[1] Published by permission of the director of the United States Geological Survey.

[2] *I. e.*, Erosion which works at the base of topographic features, undercutting them.

ANDESITIC ROCKS.

MASON'S BUTTE.

Field description.—Mason's Butte lies close to Walker River, in Mason Valley, about four miles due south from Wabuska. It is thus situated midway between the northern end of the Walker River range and the northern end of the Smith Valley and Pinenut ranges. The rocks of the butte are related to those of all these ranges, as will be shown later. The butte itself is about a mile and a half long in a northeasterly direction, and about half a mile wide. It presents from a little distance the appearance of typical volcanic rock, being distinctly thinly bedded, with red and gray zones. On the western face of the butte is a scarp two or three hundred feet high, and from here easterly there are a series of saw teeth, caused by the unequal erosion of the bands of which it is composed; then the butte sinks gradually into the plain again. The bands of igneous rock dip easterly 15° at the western end of the butte, and the dip increases to the east, so that on the eastern end they dip 30°. Here they are locally reversed and dip west, probably from movement subsequent to the eruption, which movement is also evidenced by shearing. The beds strike parallel with the longest extension of the butte (see Fig. 1).

FIG. 1.—Cross section of Mason Butte, showing alternations of course and fine textured dioritic beds. Drawn to scale. Scale, 1 inch=850 feet.

Upon examination, the rocks are found to be diorite and andesite in alternating conformable layers. Fourteen different layers of diorite were found in the half-mile section, with layers of diorite porphyry and andesite between. From a structural point of view, all these rocks grade into one another. Sometimes the gradation may be actually seen in a single bed; for example, a highly porphyritic andesite, which in the field was

taken for a diorite porphyry, was found to change gradually into a coarsely crystalline diorite; but generally the beds are separate. The coarse-grained rock contains some dark inclusions, which appear to be like the finer-grained rocks. The diorite is also associated with alaskite[1] which occurs in many large segregated masses irregularly distributed, and with a few quartz veins, also segregational. The alaskite and quartz veins are found only in the diorite; never in the fine-grained rocks. At the eastern end of the butte, also associated with the diorite, are considerable masses of hornblendite which grade into normal diorite.

Although a careful search was made, no intrusive phenomena showing that the andesites are intrusive into the interbedded diorites, or vice versa, were found. Although the whole butte is of rugged rock and entirely free from any vegetation sufficient to obscure exposures, yet the succession of the different beds is as normal and regular as in the case of sediments. The andesites are evidently similar to the Tertiary andesites which occur plentifully in the whole region round about. The conclusion reached in the field, therefore, was that Mason's Butte represents the roots of old volcanic flows, that the apparent bedding is a flow structure on a large scale, and that the coarse-grained and fine-grained rocks, the diorites and andesites, are different forms of crystallization from a single magma. Some of the fine-grained rocks are separate layers from the coarse-grained ones, while some are simply variations in them. The diorite naturally incloses portions of an earlier formed crust, which is identical with the finer-grained beds.

Microscopic evidence.—The structure and composition of typical specimens from this butte will now be described:

Hornblende-biotite-quartz-diorite[2] (117 N.).—This rock in the hand specimen is medium coarse granular and rather dark, on

[1] See *Am. Geol.*, April, 1900, p. 230. *Alaskite* is proposed as a general name for rocks consisting of quartz and alkali feldspars without essential ferromagnesian constituents.

[2] These numbers refer to the specimens in the writer's collection, and are given for the purposes of subsequent identification.

account of a liberal percentage of ferromagnesian minerals. It has the appearance of a typical granular rock. Under the microscope the structure is coarse. The largest grains are as much as 8^{mm} in diameter, and these grains, which have hypidiomorphic or idiomorphic outlines, are closely intergrown. Filling the spaces left by the intergrowth of these larger grains is a somewhat scanty mesostasis, composed of grains averaging about 1^{mm} in diameter. The minerals of the larger and the smaller grains are the same, consisting of feldspar, which is greatly in excess, and quartz, green hornblende, and biotite. The quartz is distinctly subordinate in amount to the feldspar. The feldspars were tested by the Fouqué method and gave, on sections perpendicular to both the positive and the negative bisectrices, the extinction angles for oligoclase.

Hornblende-biotite-quartz-diorite (123 N.).—This does not differ in the hand specimen to any noticeable extent from 117 N. Under the microscope also the two are essentially alike, but with a slight difference. In 123 N. the larger crystals are more abundant, so that the structure at first sight appears to be coarse allotriomorphic granular. On closer analysis the section is seen to be made up of more or less idiomorphic crystals of feldspar, green hornblende, and biotite, closely packed together, with the spaces between filled with a scanty mesostasis of quartz, feldspar, hornblende, and biotite, these grains being of all sizes, commencing with the size of the idiomorphic grains just described. In this section, as in 117 N., the quartz is a subordinate essential. The feldspar, tested twice by the Fouqué method, gives the angles for andesine-oligoclase.

Hornblende-andesite (116 N.).—This is a porphyritic rock with an abundant, greenish groundmass, and is entirely similar in appearance to the hornblende-andesites of the Pinenut range, just west of the butte. Under the microscope the groundmass is found to be holocrystalline and microgranular, consisting chiefly of allotriomorphic feldspar and hornblende. The phenocrysts reach a diameter of about 2.75^{mm}, and consist of feldspar and green hornblende. The feldspars, when tested, gave twice

the extinction angles of andesine. In this section the phenocrysts are less in amount than the groundmass.

Hornblende-andesite (118 N.).—In the hand specimen this has the appearance of a diorite closely verging upon diorite porphyry. Under the microscope, however, there is found to be, between the closely packed phenocrysts, a micro-granular groundmass, slightly finer grained than that of 116 N. It consists chiefly of feldspar with some hornblende. The phenocrysts also are chiefly feldspar, with subordinate hornblende, which is largely altered to epidote. Determinations of the feldspar show that it is oligoclase. The larger phenocrysts have an average diameter of about 2^{mm}.

Hornblende-quartz-andesite (121 N.).—This rock is similar in appearance to 118 N. It has also a fine holocrystalline granular groundmass, showing no fluxional arrangement and composed of feldspar and quartz. The phenocrysts have a maximum diameter of about 3^{mm}, and consist of feldspar, green hornblende, and subordinate quartz, the last named in large rounded or corroded crystals. The hornblende is largely altered to epidote. The feldspar, tested twice by the Fouqué method, shows the extinction angles of andesine and andesine-oligoclase.

Hornblende-quartz-andesite (120 N.).—This rock in the hand specimen is dense, greenish and fine grained, having a trap-like appearance, with small phenocrysts in an aphanitic groundmass. Under the microscope the rock is seen to be much like those just described. The groundmass is fine holocrystalline, consisting of lath-shaped feldspars and hornblende, with subordinate quartz and some pyrite and siderite. There is a slight fluxional arrangement. The phenocrysts belong to a distinct generation from the groundmass (*i. e.*, there are no transitions) and consist of feldspar, pale green hornblende, and a single large grain of corroded quartz. The phenocrysts reach a diameter of 2^{mm}. The hornblende is largely altered to calcite, chlorite, and epidote.

Hornblende-andesite (119 N.).—This is from the same bed as 120 N., and is simply a variation from it. In appearance it is

somewhat different, on account of the more abundant conspicuous feldspar phenocrysts, which are, however, very small, so that the rock resembles a miniature of 121 N., reduced three or four times. Under the microscope the groundmass is seen to have been originally glassy, but now is devitrified, and has a cryptocrystalline structure, The phenocrysts attain a diameter of about 1^{mm}, and consist of feldspar and hornblende. The feldspar, upon optical examination, proves to be oligoclase. The hornblende is mostly altered to calcite and chlorite.

Alaskite (114 N.).—This in the hand specimen is a typical, rather fine-grained, dense rock. Under the microscope the structure is hypidiomorphic granular. The grains average 1^{mm} in diameter, and consist of quartz, orthoclase, and microcline in somewhat equal proportions. The only dark minerals present are a few grains of chlorite and pyrite.

Hornblendite (124 N.).—This is a coarse-grained rock, typical of its kind, and also consists of green hornblende, with blotches of epidote. Under the microscope the structure is seen to be allotriomorphic. No other minerals are present save those mentioned, and the epidote is secondary to the hornblende. In the section studied the grains average about 3^{mm} in diameter.

Analysis of structure.—The series of rocks just described, from 117 N. to 119 N., inclusive, shows a transition, which has at one end a typical coarse granular rock and at the other a porphyritic rock with a glassy groundmass. In the intermediate stages the phenocrysts increase in numbers and somewhat in size, while the groundmass shrinks in volume and becomes also coarser. In 123 N., which is a typical granular rock only slightly removed from 117 N., these phenocrysts have increased until they nearly fill the rock, while the small portion of groundmass which remains has coarsened so that the grains are a millimeter in diameter; thus the rock at first sight appears a typical allotriomorphic granular rock, from which it is moreover not far removed.

The very slight variations of structure between any two adjacent members of this transition series shows that the differences

in condition which brought about the separation of the coarse-grained from the fine-grained rocks were relatively small. These differences are plainly longer cooling periods (and hence longer crystallization intervals) in some portions of the rock, as compared with others. The coarse granular rocks, judging from their almost complete and uniform crystallization, have crystallized entirely in their present position; the segregation from them of alaskite on the one hand, and hornblendite on the other, is additional evidence of this. The porphyritic forms, however, show generally two distinct generations, and this, with the fact that some of the phenocrysts of the first generation, especially the quartz, show corrosion and resorbtion, indicates a change of conditions; also the slight fluxional arrangement, sometimes observed, shows at least local movement. Yet the contemporaneity of the fine-grained porphyritic rocks with the granular forms, shows that the crystallization break registered by the former did not arise from any important change of position.

Composition of rocks. — The general mineral composition of rocks of all structures (leaving out the alaskite and hornblendite, which are plainly segregation products from the hornblende quartz-diorite), is the same, being a hornblende-quartz-diorite or quartz-andesite. In the andesites the quartz, where present, was plainly in process of resorbtion by the groundmass at the time of solidification, so that it is probable (from the fact the hornblende andesites and the hornblende-quartz-andesites often occur as variations of a single bed) that in those andesites which do not show free quartz the composition is the same as where they do, the quartz belonging to the first period of crystallization having been entirely resorbed.

Analyses of the rocks are as follows (analyst, Dr. H. N. Stokes):

No. 1, No. 117 N. Hornblende-biotite-quartz-diorite		No. 2, No. 120 N. Hornblende-quartz-andesite	
SiO_2	60.25	SiO_2	53.37
Al_2O_3	17.90	Al_2O_3	16.57
Fe_2O_3	3.08	Fe_2O_3	3.84
FeO	2.44	FeO	2.45
MgO	2.44	MgO	5.79
CaO	5.57	CaO	6.30
Na_2O	4.29	Na_2O	3.40
K_2O	1.89	K_2O	2.55
H_2O+	.20	H_2O+	.39
H_2O	1.24	H_2O	2.33
TiO_2	.65	TiO_2	.86
CO_2	none	CO_2	1.61
P_2O_5	.25	P_2O_5	.29
MnO	.06	MnO	.08
SrO	.07	SrO	trace
	100.33		99.83

In No. 1 the ratio of $Na_2O + K_2O : CaO = 1 : 1.1$. In No. 2 the same ratio is 1 : 1.13. These ratios are calculated from the quotient figures obtained by dividing the percentages of each by the molecular weights. Similarly in No. 1 the ratio of $K_2O : CaO$ is 1 : 4.95. In No. 2 the same ratio is 1 : 4.18.

No. 2 contains less quartz and more hornblende than No. 1, hence the decrease in silica and the increase in magnesia; otherwise the two rocks are the same.

Correlation of rocks.—As before stated, just west of Mason's Butte lies the northern end of the Smith Valley and Pinenut ranges. On crossing from Waubuska through Churchill Canyon, andesites were found which were recognized in the field as similar to those in the butte. The bedding of these rocks is nearly horizontal. They are fine-grained hornblende-andesites, often with fine holocrystalline groundmass; occasionally they vary to fine-grained diorite porphry. In higher portions of the mountains (these relatively coarse-grained lavas are exposed in the lowest cuts) the lavas are dacites and pyroxene andesites.

Andesites form the main mass of the Pinenut range at its northern end, which is separated from the Washoe district at

the southern end of the Virginia range by a comparatively narrow valley. The lavas of one range are evidently continuous with those of the other.[1] In the Washoe district have been found eruptions of hornblende-mica-andesite and quartz-andesite or dacite, corresponding exactly to that at Mason Butte. At Washoe, also, the andesite becomes, under favorable conditions, coarsely crystalline, and Messrs. Hague and Iddings[2] have noted that upon this complete crystallization quartz separates out, producing a mica-quartz-diorite.

RHYOLITIC ROCKS.

TRANSITIONS IN TEXTURE OF THE BASAL RHYOLITES OF THE PINENUT RANGE.

Field description.—The central core of the Pinenut range is made up of granitic rocks. These were examined in two localities: one southeast from Dayton, and one west from Wellington.

At the first mentioned locality, granitic rocks are exposed along an easterly facing scarp which is at the north end of Smith Valley. The rocks are all granular, so far as observed, but vary much in texture from fine to coarse; they are often porphyritic. They show a distinct banding, resembling at a distance rude stratification; this banding is due to a zonal arrangement of the rocks of different textures.

In the district west from Wellington, rhyolitie and granitic rocks are exposed in the spur just east from the Mountain House, and are of exceptional interest. Here, beneath the andesitic rocks which cover the mountain slopes, is found a highly indurated volcanic conglomerate and sandstone, apparently waterlaid, and consisting entirely of rhyolitic material. A short distance farther on, the rocks from which these detritals are derived were found in place. These original rocks show great variations, passing from a fine-grained, almost aphanitic,

[1] See "The Succession and Relation of Tertiary Igneous Rocks in the Great Basin Region," JOUR. GEOL., Vol. VIII, p. 621.

[2] Bull. 17, U. S. Geol. Surv.

rhyolite, to coarse siliceous granite and alaskite. The numberless variations are within a few feet of one another and are arranged in bands, recalling immediately the similar phenomenon in the andesitic rocks of Mason Butte. In the case of the rhyolitic rocks also there is no sign of intrusion of one into another, nor in general does there appear to be any marked gradations between the different bands at contact, the boundaries between them being fairly distinct.

It is clear in the field that the variations are chiefly textural and that the composition of all the varieties is nearly the same — that of siliceous granite or rhyolite.

In this case again, we have rocks which appear to represent the roots of old volcanics, being intermediate between completely massive plutonic igneous rocks and superficial fine-grained volcanics. They must have suffered a flowage resulting in the formation of this peculiar streaky structure, while the great variations in texture in the different bands show crystallization at points still far removed from the surface.

Of the different rock varieties in the locality west from Wellington the following will be briefly described.

Biotite-rhyolite (164 N^a.).—Structure porphyritic; groundmass cryptocrystalline, probably devitrified glass. The phenocrysts are of all sizes, the larger ones grading down to those which vanish in the groundmass. They are of feldspar, quartz, and biotite, the latter decomposed. The feldspar was determined to be largely albite and oligoclase-albite, although there is some orthoclase. The largest phenocryst of feldspar measures $2\frac{3}{4}$ mm in diameter; the largest one of the quartz, $1\frac{1}{2}$ mm. The rock contains angular fragments of finer grain. Some of these seem to be devitrified rhyolitic glass, while others are fragments of more basic lava, probably andesite — these latter show small lath-shaped feldspar phenocrysts in a glassy semi-devitrified groundmass.

Biotite-rhyolite (165 N^a.).—In this specimen the groundmass becomes slightly coarser than in the preceding specimen and is very fine microgranular. It also becomes more scant than in

164 N^a, on account of the multiplication of phenocrysts, which show the same great variety in point of size as the rock just described. The same angular fragments of more basic lava also occur. The phenocrysts are quartz, orthoclase, and a striated feldspar; the latter tested twice by the Fouqué method proves to be albite. The orthoclase was optically determined as such.

Rhoylite (162 N^a.).—In this rock the groundmass is fine holocrystalline, coarse enough to enable one to distinguish the mosaic of quartz and feldspar. This groundmass contains the same fragments of more basic lava that have already been described, and also encloses broken phenocrysts of mostly unstriated feldspar.

Granite-porphyry, fine-grained (169 N.).—In this rock the groundmass is fine granular, sometimes granophyric, and conrists chiefly of quartz and orthoclase. The phenocrysts are abundant and consist of quartz and feldspar, with chlorite and epidote which are derived from the decomposition of ferromagnesian minerals. The feldspar phenocrysts are partly orthoclase and partly a striated feldspar, which, determined by the Foqué method, proves to be oligoclase-albite.

Biotite-granite, medium-grained (171 N.).—In this rock the grains are of two distincts sizes, one many times larger than the other. The larger grains have a tendency to idiomorphism, the smaller grains to allotriomorphism. The smaller grains are included between the interlocking larger ones and may be considered as forming an overgrown groundmass, partly crowded out by the multiplication and joining of phenocrysts, which are represented by the larger grains. The minerals of the rock are quartz, feldspar, biotite, and magnetite. The feldspar is almost entirely orthoclase, with some microcline and albite.

Granite, coarse (175 N.).—The structure of this rock is like that of the preceding, only coarser. It contains many perfect idiomorphic crystals of feldspar, often touching and almost interlocking, and smaller crystals of bleaching biotite and ragged pale green hornblende, the last perhaps secondary. These minerals

are in general cemented by a mesostasis of coarse allotriomorphic quartz, which often includes or is intergrown with, in poikilitic fashion, smaller crystals of feldspar, pale green hornblende, and sphene. The feldspar included in the quartz sinks to very small dimensions, whereas the ordinary feldspar grain is very large. The structure may be regarded as the coarsening of the porphyritic structure, or at least closely related to it by reason of the two generations. The large feldspar crystals are partly orthoclase, but are chiefly finely striated. Optical determinations of the striated crystals show microcline-anorthoclase and albite.

Granite, coarse (172 N.).—This rock is almost entirely like 175 N, and has a good deal of the peculiar structure of this rock, but in general is more hypidiomorphic granular or truly granitic.

Analysis of the structures of the granite-rhyolites.—The analysis of the structure of the granites and rhyolites just described helps toward a better understanding of their relation.

164 N (a). Here are phenocrysts of all sizes, gradually shrinking in size to the glassy (sometimes slightly devitrified) groundmass; *i. e.*, the crystallization, instead of belonging to one or two distinct generations, represents many generations, not separable from one another. This is a proof of gradual and equable hardening. It shows that the viscosity increased very slowly and regularly to the point of final complete solidification, the newer crystals having progressively smaller fields of crystallization.

165 N(a). This is like 164 N(a) except that the groundmass diminishes, on account of multiplication of phenocrysts. This marks a longer cooling period than 164 N(a), so long as almost to permit of total crystallization as relatively large crystals.

162 N(a). In this section the feldspar phenocrysts are not connected by gradual transitions with the groundmass, which is slightly coarser than that of 165 N(a) and is much more abundant. We have, therefore, two distinct generations of crystallization, and this, together with the frequently broken character

of the phenocrysts, indicates a break in the crystallization, evidently resultant from a movement of the solidifying mass. The order of events in this section was, therefore, (1) comparatively slow crystallization of feldspar; (2) flowage, producing a change of conditions; (3) medium rapid cooling, bringing about the uniform moderately fine crystallization of the rest of the rock.

169 N. Here the line between the abundant phenocrysts and the fine-grained groundmass is, in general, distinct, for although there are transitions between the two they are not so abundant as in rocks like 164 N(a) and 165 N(a). This connotes a shorter period of first crystallization (when the phenocrysts were formed) than does 165 N(a), then a more rapid cooling than 165 N(a) to a certain point, then a slower rate of crystallization, permitting the formation of the uniform fine granular structure.

171 N. The structure of this connotes a long period of slight viscosity, during which the crystals of quartz and feldspar could grow until they touched and sometimes interlocked. The difference in size between these crystals and the grains of the groundmass or mesostasis which fills the space between them, implies a slight break or change of conditions, after which was again a comparatively slow uniform crystallization of the rest of the rock, producing an even allotriomorphic granular structure. There are then two distinct generations of crystals. The resulting structure is entirely similar to the ophitic structure of diabases, save that in these siliceous feldspars the forms are not so elongated, and so the structure is not so striking. The structure of this specimen, however, differs from the typical granitic structure in the same way that a diabase differs in structure from a gabbro. A longer period for the first crystallization, reducing the mesostasis to a still smaller percentage, would give the aplitic structure, where the idiomorphic crystals are predominant and occupy the greater portion of the section.

175 N. This is like 171 N, but in general the mesostasis of comparatively small grains is wanting, being replaced by a filling of coarse allotriomorphic quartz. In this case the conditions of crystallization have evidently been gradual throughout. The

rock crystallized slowly under conditions of slight viscosity. After the exhaustion of the feldspathic material residual quartz crystallized in the remaining spaces.

Tabulation.—The following table shows the gradation from fine-grained rhyolite to granite:

Specimen No.	Character of groundmass.
164 N (a)	Glassy.
165 N (a)	Cryptocrystalline.
162 N (a)	Finely microgranular.
169 N	Microgranular; micropegmatic.
171 N	Granular; grains average .5^{mm} diameter.
172 N	Granular; grains average .5^{mm} diameter.
175 N	Large quartz grains, average 2.25^{mm}.

Analyses.—The following are analyses of the two fairly typical specimens as above described (analyst, Dr. H. N. Stokes):

(1) 168 N. Biotite rhyolite. Like 165 N (a).		(2) 172 N. Siliceous granite.	
SiO_2	71.49	SiO_2	75.09
Al_2O_3	15.06	Al_2O_3	13.51
Fe_2O_3	1.51	Fe_2O_3	1.13
FeO	.88	FeO	.08
MgO	.35	MgO	.18
CaO	1.54	CaO	.91
Na_2O	4.19	Na_2O	3.58
K_2O	3.39	K_2O	4.71
H_2O-	.16	H_2O-	.17
H_2O+	.88	H_2O+	.25
TiO_2	.20	TiO_2	.22
CO_2	none	Co_2	none
P_2O_5	.08	P_2O_5	.04
MnO	trace	MnO	trace
SrO	trace	SrO	trace
	99.73		99.87

It will be seen that No 2 is slightly more siliceous than No. 1; nevertheless the two rocks are intimately related. In No. 1 the relation of $K_2O + Na_2O : CaO = 1 : .26$. In No. 2 the same ratio equals 1 : .15. Similarly, in No. 1 the relation of $K_2O : CaO = 1 : .75$. In No. 2 the same ratio equals 1 : .32.

Conclusions.—Many of the bands in this granite-rhyolite series show by their structure that they have undergone no break

in crystallization from beginning to end. The rocks have evidently crystallized entirely in their present position, and the slow hardening which is ordinarily indicated shows that this point of consolidation was originally some distance from the surface.

In other specimens there have been slight breaks, bringing about two, three, or more generations of crystals which in the rocks near by are not distinguishable. These minor breaks were due to slight migrations of material in certain bands, which flowed slightly during the process of cooling, as is proved by the angular fragments of finer-grained lava which they contain and by the occasional broken condition of the phenocrysts.

As explanation of the difference in crystallization between the granular bands and the intercalated fine-grained ones, it must be remembered that those bands which were affected by flowage must have been at the time those possessing least viscosity and consequently those which were least crystallized. The final crystallization of these bands, therefore, took place at a later period than that of granular bands, at which period the rate of solidification was very likely more rapid. It is probable, moreover, that the movement of flowage brought on of itself a more rapid crystallization than if the rock had been undisturbed, and that thus the finer-grained groundmass orginated. The same suggestions hold good for the similar phenomena, already described at Mason Butte.[1]

[1] In connection with the conclusion above arrived at, *i. e.*, that the phenocrysts of the rocks were formed practically in place, compare the papers by Professor Pirsson and Professor Crosby. (*Am. Jour. of Sci.*, Vol. VIII, April, 1899, p. 271, "On the Phenocrysts of Intrusive Igneous Rocks," and *American Geologist*, Vol. XXV, No. 5, May, 1900, "On the Origin of Phenocrysts and the Development of Porphyritic Texture in Igneous Rocks.")

Professor Pirsson argues that the phenocrysts of intrusive rocks are not necessarily intratelluric, and that there is no necessity of more than one period of crystallization even for porphyritic rocks. From the fact that contact zones are often without phenocrysts, while the rest of the rock contains them; that in a contemporaneous complex of dikes and sheets some may have phenocrysts while others do not; from observed cases where fluidal phenomena show that phenocrysts have developed after the flowage; from the arrangement of the crystals of the groundmass around some phenocrysts, showing that these crystals have been crowded and shoved during the growth of the larger crystals; and from the fact that many granites (which have generally been considered intratelluric) contain very large phenocrysts, Professor Pirsson

TRANSITIONS OF TEXTURE IN THE GRANITE-RHYOLITES OF THE QUINN CANYON RANGE.

Field description.—The Quinn Canyon range lies a long distance east of all the other localities which have been described, being almost due south from Eureka and nearly west of Pioche. The whole southern portion of the range is buried in rhyolitic flows.[1] The range was examined by the writer at its northern end, where the Paleozoic core of the mountains emerge from the volcanic covering. On the western side of the range, near the contact of the Paleozoics with the rhyolite, the stratified rocks are pierced by numerous great dikes, which vary from coarse to fine in texture. These dike rocks seem similar in composition, and sometimes in texture, to the rather massive rhyolite which forms the hills to the west of this locality.

Microscopic description.—A specimen of the main rhyolite examined under the microscope has the following characteristics:

Rhyolite (241 N.).—This rock has phenocrysts of all sizes,

reasons that phenocrysts are not necessarily of a distinct crystallization period as compared with the groundmass, but may in some cases be formed in place. Professor Pirsson advances the explanation that a comparatively rapid fall of temperature and decrease of hydration, resulting in a viscosity augmenting in an increasing ratio, may produce monogenetic phenocrysts (that is, phenocrysts which occur only in a single generation). Recurrent phenocrysts (that is, those occurring in more than one generation) he explains as due to mass action, believing that minerals which are present in very large quantity are especially active crystallizers.

Professor Crosby believes that no sudden changes of temperature, hydration, or pressure, are necessary for the formation of phenocrysts. He believes that in a gradually consolidating rock the crystallization first established may be brought to a close by the gradually increasing viscosity and that after passing this critical point new zones of crystallization will be established, of much smaller field, and at this point the groundmass begins and the phenocrysts end. If the rate of cooling is still slower, an allotriomorphic granular texture results, while if the rate is more rapid the texture may be glassy or nearly so.

The deductions of the writer, given above, agree with those of the authors cited in this, that phenocrysts may be formed in place. His observations, however, go to show that where cooling is strictly uniform there will be no distinct generations, but a gradual transition from phenocrysts to groundmass; whereas, if there are distinct generations, they are brought about by breaks in the conditions of consolidation, even though these breaks be comparatively slight.

[1] G. K. GILBERT, *Survey West of the 100th Meridian;* Vol. III, Geology, p. 122.

from 1½ mm in diameter grading down into groundmass, which is cryptocrystalline, probably a devitrified glass.

Two selected specimens of the dike rocks have the following characteristics:

Biotite-granite-porphyry, near rhyolite (243 N.).—Like 241 N, this rock has phenocrysts of all sizes, from 1½ mm in diameter down to the groundmass. There are, however, more phenocrysts in this rock than in the one just described. As in 241 N, the phenocrysts have no fluxional arrangements, but a divergent one. The groundmass is fine holocrystalline allotriomorphic ganular.

Biotite-granite (242 N.).—This rock consists of grains of all sizes from 6½ mm in diameter down to the very minutest dimensions. The smallest ones, which are very abundant, are about .02 to .03 mm in diameter. There is a tendency to idiomorphism throughout. The smaller sizes of crystals act as mesostasis for the larger ones, and these have a mesostasis of the still smaller ones. The essential minerals are quartz, othoclase, and biotite, with accessory hornblende, titanite, magnetite, and a little striated feldspar.

Analyses.—The chemical composition of these rocks is as follows (analyst, Dr. H. N. Stokes):

(1) No. 214 N, Siliceous Rhyolite.		(2) No. 242 N, Biotite Granite.	
SiO_2	74.67	SiO_2	71.48
Al_2O_3	13.25	Al_2O_3	13.00
Fe_2O_3	1.06	Fe_2O_3	1.25
FeO	.18	FeO	1.55
MgO	trace	MgO	.95
CaO	1.26	CaO	2.60
Na_2O	3.99	Na_2O	2.60
K_2O	4.62	K_2O	4.24
H_2O-	.18	H_2O-	.20
H_2O+	.22	H_2O+	1.24
TiO_2	.07	TiO_2	.43
CO_2	.79	CO_2	.30
P_2O_5	.06	P_2O_5	.09
S	trace	S	none
MnO	none	MnO	.09
BaO	none	BaO	.09
SrO	none		
	100.35		100.11

In No. 1 the relation $K_2O + Na_2O : CaO = 1 : .2$. In No. 2 the same relation equals 1 : .53. In the same way, in No. 1, $K_2O : CaO = 1 : .46$. In No. 2 the same ratio equals 1 : 1.

Conclusions.— In the field the evident relation of the dikes to the rhyolite led to the inference that they had been the feeders of the extrusive rock. Under the microscope the composition of the three rocks is found to be the same, and the structure shows variations indicating no great differences in the conditions of cooling. The structure is identical with that of certain specimens of rhyolite-granite just described from the Pinenut range, and therefore need not be analyzed again. Briefly, in all three it indicates complete crystallization in one place, with no interrupting movement. The period of consolidation for 241 N was comparatively short, that of 243 N somewhat longer, and that of 242 N markedly greater than 243 N.

ANALOGOUS CASES OF VARIATIONS OF TEXTURE IN OTHER PARTS OF THE GREAT BASIN.

In the Washoe district, Nevada, not far from the first locality decribed by the writer, Messrs. Hague and Iddings[1] found a gradual transition from pyroxene andesites with glassy groundmass to pyroxene-diabase with coarse granular structure. In the Sutro Tunnel they found coarsening of the crystallization as the tunnel nears the core of Mount Davidson, so that at one end the rock may be called andesite and at the other end diabase. They also discovered like transitions between andesite and granular diorites.

Similarly they found that the earlier hornblende-andesite passes into diorite, while the later hornblende-mica-andesite changes into mica-diorite in such a way that the two rocks are inseparable. They concluded that a dike of so-called diabase is a variation of the basalt, which was one of the latest extrusions.

In short, according to these writers, the coarse holocrystalline rocks of the Washoe district are chiefly Tertiary, and are partly extrusive and partly closely connected with extrusives of similar

[1] Bull. 17, U. S. Geol. Surv.

composition. Another interesting conclusion is that the change between the lava texture and the granitoid texture consists chiefly in the coarsening of the groundmass.

In 1899, Messrs. Tower and Smith described textural transitions in the Tintic range in Utah, which lies within the petrographic province of the Great Basin and is situated southward from Great Salt Lake.[1] In this district is found pyroxene andesite or perhaps more properly latite, which is an effusive rock and is closely associated with granular monzonite. There are all variations of texture between andesite with glassy groundmass to that with a holocrystalline groundmass; from this to closely similar rocks, also with holocrystalline groundmass, which are called monzonite porphyry; and from these through panidiomorphic granular phases to those of hypidiomorphic granular structure.

CONCLUSIONS.

In the Great Basin, particularly in Nevada, we have Tertiary extrusive rocks which show transitions from a granular structure with glassy groundmass. The different phases are often intimately associated, and structural analysis shows that the differences of crystallization which brought about these variations were slight, a relatively small decrease of the rate of cooling being sufficient to allow the formation of the holocrystalline instead of the porphyritic structure.

Transitions similar to those found in the Great Basin have been sparingly chronicled elsewhere. These appear to become rare in proportion as the rocks become siliceous. This is so because with a given relatively rapid rate of cooling a magma of basic composition will consolidate with a holocrystalline structure, while a siliceous magma will become fine-grained and porphyritic. We have accordingly many instances of holocrystalline diabases which are certainly extrusive, and of similar rocks in rather fresher condition (generally due to their being younger) which have been called dolerites. In the more siliceous rocks such textural transitions are rare in

[1] *Nineteenth Ann. Rept. U. S. Geol. Surv.*, p. 656.

effusive bodies, but further down, at the roots of volcanoes, the conditions are such as to allow viscosity to increase with the same slowness that it does with a more rapid cooling rate in more basic rocks. Hence with increasing acidity we find the coarser grained varieties further removed from the surface. In general, however, it is plain that a granular rock is not necessarily a deep-seated one, in the formerly accepted sense of the word.

Another conclusion which may be made from the foregoing studies is, that the more important structures are not peculiar to particular rocks. The porphyritic and the coarse granular allotriomorphic or hypidiomorphic structures are already recognized as characterizing all rocks, of whatever chemical composition. Also the aplitic structure, or that in which idiomorphic minerals (which are the same as the phenocrysts of the porphyries) form the greater bulk of the rock, has been recognized as universal by Rosenbusch, who has described it in granitic rocks and in all intermediate ones down to gabbros; thus his rock terms include syenite aplite and gabbro aplite. The ophitic structure has been generally supposed to be characteristic of diabases, and without question is here best exhibited, on account of the rate of solidification which the basic composition of a magma entails and also because the elongated forms of the basic feldspars make the structure prominent. The foregoing studies, however, show that this structure is intermediate between the porphyritic and the aplitic structures, representing a stage in crystallization when the idiomorphic crystals (or phenocrysts, as they are called in the porphyries) have multiplied and grown so that they interlock; and that like these other structures it may occur in any rock. In the granites it is not so striking as in more basic rocks, on account of the blunt form of the alkaline feldspars which form the first generation of crystals, but it is nevertheless present in some of the granites which have been studied. In diorites the ophitic structure has been occasionally described.[1]

[1] ROSENBUSCH, *op. cit.*, p. 256; ZIRKEL, *Lehrbuch der Petrographie*, 2d ed., p. 483.

The writer, of course, interprets the term ophitic in its broader and not in its narrower sense, accepting it as meaning a structure where a network of interlocking, divergent, comparatively large feldspar crystals is filled in by grains of much smaller dimensions, whatever the nature of these grains may be. He does not interpret it as meaning that the mesostasis is necessarily augite. He finds grounds for this broader acceptation in the writings of Rosenbusch, Zirkel, and others. Rosenbusch applies the term ophitic[1] to diabases where the mesostasis is not augite, but an aggregate of primary quartz and feldspar.

Therefore, the glassy, fine porphyritic, coarse porphyritic, ophitic, aplitic and hypidiomorphic granular structures may occur in any rocks. They pass by gradual transitions into one another and are dependent upon relatively very slight differences in conditions of cooling. All may be formed without any marked migration of the consolidating rock.

These conclusions are important in considering rock classification, as showing that structure cannot be made the element of greatest importance. Granites, granite porphyries, granite aplites and rhyolites, for example, must not be separated, but put as closely together as possible, and the same is true of diabases, diabase porphyrites, diabase aplites, and basalts.

J. E. SPURR.

[1] *Mikroskopische Physiographie*, 3d ed., p. 1117.

THE FOYAITE-IJOLITE SERIES OF MAGNET COVE: A CHEMICAL STUDY IN DIFFERENTIATION.

INTRODUCTORY.

SOMETIME since I published a paper[1] on the "Igneous Complex of Magnet Cove," in which it was shown that the main types found there were arranged in a very regular series from the center to the periphery of the mass, and that this was an excellent example of the differentiation of a magma in place, presenting, however, the anomaly of being less "basic" at the borders than at the center. It was also remarked that the analyses then available "vary continuously in one direction, with scarcely a break or abnormality of any kind."[2]

Since then several considerations led to the belief that a new and more detailed chemical examination of the main rock types was desirable. Several of these, notably the "leucite-porphyry" and ijolite, are representatives of rock groups of great theoretical importance, complete analyses of which are highly desirable. In this respect many of those published by Williams[3] are defective, the non-determinations of the rarer constituents being largely due to the fact that the importance of completeness in rock analysis was not recognized at the time they were made.[4]

Such a reëxamination seemed to be the more desirable, since in a recent paper Pirsson[5] has shown that the rocks occurring in the Little Belt Mountains of Montana form an extremely regular series. By plotting the constituent oxides on an abscissal basis of distance from the center of the mass, he arrived at the conclusion in this case that, "given the percentage of one element, the chemical composition of any rock of the series to within a

[1] *Bull. Geol. Soc. Amer.*, Vol. XI, p. 389, 1900.

[2] *Op. cit.*, p. 403.

[3] J. F. WILLIAMS, "Igneous Rocks of Arkansas." *Ann. Rep. Geol. Surv. Ark.* Vol. II, 1890.

[4] *Cf.* J. C. BRANNER, in Williams, *op. cit.*, p. xiv.

[5] L. V. PIRSSON, *Twentieth Ann. Rep. U. S. Geol. Surv.*, Part II, p. 569 ff., 1900.

fraction of 1 per cent, can be deduced from the diagram." This instance is the first in which the differentiation of a mass of magma is rendered capable of exact mathematical treatment and proof, and its great theoretical interest and importance is obvious. The conditions of the locality were such that it was thought that the Magnet Cove complex might furnish another favorable example of the same kind, a hope which was justified by the results obtained, as will be seen later.

The analyses of six of the representative plutonic rocks of Magnet Cove, as well as two of Fourche Mountain, were therefore undertaken, with the determination of the rarer constituents which might be present. For petrographic descriptions the reader is referred to the two papers cited above.

In this connection I would express my full endorsement of Pirsson's remarks[1] on the importance of good and complete analyses, which are absolutely essential for such mathematical discussion, and with him deplore their comparative rarity. To many petrographers, any collection of figures which foots up within 98 and 102 per cent. is a usable analysis, even though the results are at variance with the mineralogical composition, and some of the obviously important constituents are not estimated. It is not realized that such "analyses" do far more harm than good to the science. From this point of view alone, the excellent work of Dr. Hillebrand and the other chemists of the United States Geological Survey is of inestimable value, as they have set a standard to fall short of which in any marked degree should be accounted a petrographic sin. Let me be the first to confess "*peccavi*."

ANALYSES.

Pulaskite.— The specimen of this type was collected at the Little Rock Granite Company's quarry, at Fourche Mountain, near Little Rock, the type locality. In I is given my analysis, in II that of R. N. Brackett, as quoted by Williams. The two do not differ materially, I showing rather less Fe_2O_3 and CaO and more FeO, MgO, and alkalis, though the ratio of

[1] L. V. PIRSSON, *op. cit.*, p. 578.

	I	II		I	II
SiO_2	60.20	60.03	TiO_2.....	0.14	....
Al_2O_3.....	20.40	20.76	ZrO_2.....	trace	....
Fe_2O_3	1.74	4.01	P_2O_5	0.15	0.07
FeO	1.88	0.75	SO_3.....	0.13	....
MgO.....	1.04	0.80	Cl.....	0.09	....
CaO.....	2.00	2.62	S.....	none	....
Na_2O.....	6.30	5.96	MnO.....	trace	trace
K_2O.....	6.07	5.48	BaO	trace	....
$H_2O(110°+)$	0.23	0.53			
$H_2O(110°-)$	0.10	0.06		100.47	101.07
C_2O.....	none	....			

I. Pulaskite, Fourche Mountain. Washington, analyst.

II. Pulaskite, Fourche Mountain. Brackett, analyst. WILLIAMS, *op. cit.*, p. 70.

$Na_2O : K_2O$ is about the same in both, being 1.57 in I and 1.66 in II. The specimen analyzed by Brackett apparently contained a little more acmite, though the variations are scarcely more than are to be expected in different specimens from the same mass.

Analysis I can be calculated out as below. There is apparently an excess of Al_2O_3, amounting to about 4 per cent. in this, as well as in II, which it is difficult to account for. It does not seem to be due to kaolinite or hydronephelite, as the rock is too fresh, and there is no muscovite present. Such an excess of Al_2O_3 above $(Na_2O+K_2O) - Fe_2O_3$ may be observed in many analyses of nephelite-syenites, if the Fe_2O_3 is calculated as acmite, and no anorthite molecule is assumed to be present. Among these are some by Hillebrand, and there is no reason to suppose that this peculiarity is due to errors of analysis. It is a feature of this group of rocks which seems to call for investigation, and may possibly be connected with the occurrence of corundum in the nephelite-syenites.

Orthoclase - - - - - -	35.1
Albite - - - - - - - -	39.8
Nephelite - - - - - - -	3.1
Sodalite - - - - - - -	1.2
Aegirite - - - - - - -	5.1
Hornblende, diopside, and biotite - -	11.0
Apatite - - - - - - -	0.5
Extra alumina - - - - - -	4.2
	100.0

Pulaskite (*Foyaite*).—This is Williams's "gray granite," the specimen coming from Braddock's quarry, on Fourche Mountain. My analysis is given in I below, with that of W. A. Noyes as quoted by Williams in II. The two are closely alike in all

	I	II		I	II
SiO_2	60.13	59.70	CO_2	none	....
Al_2O_3	20.03	18.85	TiO_2	1.15	....
Fe_2O_3	2.36	4.85	ZrO_2	0.05	....
FeO.....	1.33	....	P_2O_5	0.06	....
MgO	0.76	0.68	SO_3	0.14	....
CaO.....	0.87	1.34	MnO.....	trace	....
Na_2O.....	6.30	6.29	BaO.....	trace	....
K_2O.....	5.97	5.97			
H_2O(110°+)	1.41	1.88		100.72	99.56
H_2O(110°−)	0.16	....			

I. Pulaskite, Braddock's quarry, Fourche Mountain. Washington, analyst.
II. Pulaskite ("Foyaite"), same locality. Noyes, analyst. WILLIAMS, *op. cit.*, p. 81.

respects except Al_2O_3, which is about 2 per cent. higher in I, as about 1 per cent. of TiO_2, and a trace of P_2O_5 must be deducted from the Al_2O_3 of II.

The analysis (1) calculates out as follows, and it is evident that there is no essential difference between this rock and the last mentioned.

Orthoclase -	28.6
Albite - - -	39.0
Nephelite - -	6.2
Nosean - -	1.2
Kaolin - -	7.5
Aegirite - -	6.9
Biotite - -	7.9
Titanite - -	2.7
	100.0

Foyaite.—What seemed to be an average specimen of the occurrence at Diamond Jo quarry, Magnet Cove, was chosen for analysis. No pyrite was visible, though the analysis shows a trace of sulphur. One or two small garnets were seen in one section, which mineral is not mentioned by Williams as an accessory.

Apart from the determination of minor constituents, my analysis (I) does not differ materially from that of Brackett

	I	II	I	II	
SiO_2	53.09	53.38	TiO_2	0.11	....
Al_2O_3	21.16	20.22	ZrO_2	0.04	....
Fe_2O_3	1.89	1.56	P_2O_5	0.15	....
FeO	2.04	1.99	SO_3	none	....
MgO	0.32	0.29	Cl	0.02	....
CaO	3.30	3.29	S	0.08	1.77[1]
Na_2O	6.86	7.89	MnO	0.20	trace
K_2O	8.42	6.21	BaO	0.61	....
H_2O(110°+)	1.13			100.48	100.03
H_2O(110°−)	0.24	3.43			
CO_2	0.82				

I. Foyaite, Diamond Jo quarry, Magnet Cove. Washington, analyst.

II. Foyaite, same locality. Brackett and Smith, analysts. WILLIAMS, Sp. gr. 2.599 at 26°C., *op. cit.*, p. 238.

and Smith (II), except in the presence in the latter of nearly 2 per cent. of pyrite, and in the alkalis. I gives a ratio of $Na_2O : K_2O$ of 1.3, while in II it is 1.92. The amount of BaO in I is high, and is noteworthy since it is found only in traces or not at all in the other rocks. It probably belongs with the abundant orthoclase, since other cases are known of BaO partially replacing K_2O in the feldspar of alkaline rocks. The analysis calculates out thus:

Orthoclase	51.8
Nephelite	20.3
Cancrinite	13.1
Aegirite	5.7
Diopside	8.6
Titanite and pyrite	0.5
	100.0

It is seen that this bears out Williams's remark that "the orthoclase is perfectly free from isomorphous mixtures of other feldspars." It is indeed somewhat remarkable that the albite molecule should be entirely lacking, or almost so, in a rock containing so much soda. It seems to be characteristic of the

[1] FeS_2.

Magnet Cove rocks that albite, as well as anorthite and hornblende, are of very limited occurrence.

Covite (*"Shonkinite"*).—The specimen of this rock, which is Williams's "fine grained syenite," came from below the schoolhouse on the western border of the Cove, and the analysis was published in my former paper. It is repeated here, with the addition of P_2O_5, which has been determined since. Several analyses of analogous rocks are also given.

	I	II	III	IV	V
SiO_2	49.70	44.65	47.61	48.98	46.99
Al_2O_3	18.45	13.87	14.26	12.29	17.94
Fe_2O_3	3.39	6.06	4.90	2.88	2.56
FeO	4.32	2.94	4.07	5.77	7.56
MgO	2.32	5.15	2.62	9.19	3.22
CaO	7.91	9.57	8.71	9.65	7.85
Na_2O	5.33	5.67	6.70	2.22	6.35
K_2O	4.95	4.49	4.08	4.96	2.62
H_2O (110°+)	1.09	2.10	1.89	0.56	0.65
H_2O (110°−)	0.25	0.95	0.26	0.26	....
CO_2	....	0.11	....	....	....
TiO_2	1.33	0.95	1.38	0.98	0.94
ZrO_2	....	....	0.18	....	....
P_2O_5	0.40	1.50	1.38	0.98	0.94
SO_3	....	0.61	....	....	....
Cl	....	trace	0.37	....	....
F	....	....	trace	0.22	....
S	....	....	0 03	....	....
MnO	trace	0.17	0.30	0.08	trace
BaO	....	0.76	0.41	0.43	none
SrO	....	0.37	0.36	0.08	....
	99.44	99.99	100.68	99.99	99.60

I. Covite, Below Schoolhouse, Magnet Cove. Washington, analyst. *Bull. Geol. Soc. Amer.*, Vol. XI, p. 399, 1900.

II. Theralite, Gordon's Butte, Crazy Mountains, Montana. Hillebrand, analyst. J. E. WOLFF, *Bull. No. 150* U. S. Geol. Surv., p. 201, 1898.

III. "Tinguaite," Two Buttes, Colo. Hillebrand, analyst. *Bull. 148* U. S. Geol. Surv., p. 182, 1897.

IV. Shonkinite, Yogo Peak, Little Belt Mountains, Montana. Hillebrand, analyst. WEED and PIRSSON, *Am. Jour. Sci.*, Vol. L, p. 474, 1895.

V. Essexite, Salem Neck, Mass. Washington, analyst. JOUR. GEOL., Vol. VII, p. 57, 1899.

The mineralogical composition of these rocks is such that their calculation must, of necessity, be arbitrary and only

approximate, but those of I, II, IV, and V may be very roughly reckoned out, as below, that of IVa being Pirsson's calculation.

	Ia	IIa	IVa	Va
Orthoclase	29.3	29	25	16.3
Albite	22.8	..	10	13.3
Anorthite	....	..		17.2
Nephelite	9.0	23	..	20.1
Haüyne	....	4	..	....
Aegirite	4.5	4	..	3.7
Diopside	9.0	25	35	3.7
Hornblende	18.8	..	5	7.2
Biotite	....	..	18	....
Olivine	....	2	7	9.2
Magnetite	2.5	7	..	4.3
Titanite	3.1	2	..	4.0
Apatite	1.0	4	..	1.0
	100.0	100	100	100.0

In my former paper I discussed briefly the position of this rock in classification, and provisionally put it with the shonkinites. At that time the mineralogical composition had not been calculated, and this position was assigned to it because it resembled Pirsson's shonkinites, except in the presence of nephelite and of hornblende instead of biotite, and also because it came under Rosenbusch's definition[1] of these rocks, whose essential features according to him, are the presence of abundant dark minerals along with nephelite and orthoclase. As was also remarked, it cannot be put with the essexites or theralites (although chemically closely resembling these), on account of the lack of plagioclase.

In this connection it is of great interest to note the fact that, in his latest description[2] of typical theralite, J. E. Wolff states that there is nothing which can strictly be called soda-lime feldspar present. Indeed this fact is evident from a consideration of the analyses by Hillebrand, published in the same place. The name theralite, therefore, cannot be applicable to Wolff's Montana rocks, or else its definition must be changed.

[1] ROSENBUSCH, *Elemente der Gesteinslehre*, p. 174, 1898.

[2] *Bull. U. S. Geol. Surv.*, No. 150, p. 197, 1898.

It will be seen that, though the covite and the theralite of Wolff resemble each other in qualitative mineralogical composition, as both are composed essentially of alkali-feldspar, nephelite and ferromagnesian minerals, and that both are distinctly leucocratic in character, yet that in a quantitative mineralogical way they are decidedly different. The feldspathic constituents of the covite are very largely feldspar, with only accessory amounts of nephelite, while the theralite shows about as much feldspathoid as feldspar. The calculation of the latter cannot be exact, since some of the soda goes into the feldspar, but this must be small, and cannot affect the result to any great extent. It is evident, then, that the name of theralite is not appropriate for the Magnet Cove rock, though it might be used in the present very vague and loose method of classification, based largely on qualitative mineralogical composition.

A comparison of Pirsson's descriptions[1] with Rosenbusch's definition of shonkinite indicates that the latter has been apparently laboring under a misapprehension of the former's descriptions, and that his definition does not cover the rocks as Pirsson described them. Pirsson expressly states in each case that nephelite is either entirely absent or present only in mere traces, which does not coincide with the definition which makes nephelite an essential constituent.

Although resembling each other in many ways, yet there are certain striking differences between the analysis of the Magnet Cove rock and those of shonkinite. In SiO_2, iron oxides, CaO and K_2O they are closely alike, but in the Magnet Cove rock Al_2O_3 and Na_2O are higher and MgO lower. Indeed the calculations of the mineralogical composition, though that of Ia is only approximate, show clearly that while the "covite" is distinctly leucocratic the shonkinite is as decidedly melanocratic. A similar distinction will be pointed out between the "leucite-porphyry" and missourite. In this respect the rock under consideration resembles the typical essexite, though here again there is a distinct difference in the amount of K_2O, in the essexite this being

[1] L. V. PIRSSON, *Bull. Geol. Soc. Am.*, Vol. VI, p. 408, 1895; *Am. Jour. Sci.*, Vol. L, p. 474, 1805; *Am. Jour. Sci.*, Vol. I, p. 358, 1896.

much lower, and plagioclase entering to a very considerable extent.

For this leucocratic holocrystalline combination of orthoclase (alkali-feldspar) and less nephelite, with hornblende and aegirite-augite, of granitic structure, and with a composition like that given in the analysis above, I would propose the name of Covite. If only the qualitative, not the quantitative, mineralogical composition be considered, the covites may be called basic nephelite-syenites or foyaites. But the whole tendency of modern petrography is, rightly, against this narrow view of rock classification, and the use of a new name seems to be abundantly justified. In ordinary typical foyaites the alkali-feldspars and nephelite, etc., make up from 75 to 90 per cent. of the rock, the dark minerals consequently only from 10 to 25 per cent. In the covites, on the other hand, while the type is rather leucocratic, the light and dark minerals are present more nearly in the same amount, and these rocks might justly be called "mesocratic."

As a matter of fact, accepting Pirsson's definition of shonkinite as the standard (viz., melanocratic combination of alkali-feldspar with pyroxene, etc.), the covites are the rocks which correspond to Rosenbusch's definition of shonkinite. A similar rock, which also belongs here, is that the analysis of which is given in III, and which Cross provisionally called a "tinguaite."

Arkite ("*Leucite-porphyry*").—The specimen which was selected for analysis came from an exposure a little to the northeast of and above Diamond Jo quarry. Judging from the other specimens which I collected around the area, it seemed to be representative and an average specimen of the occurrences. A good sized hand specimen was used for the analysis, so as to obtain a fair sample of this rather coarsely porphyritic rock.

The results, given in I, were rather surprising in comparison with the analysis by W. A. Noyes of another specimen from the neighborhood (II). Not only is SiO_2 much lower, but MgO is a little higher, CaO much more so, and, though the total amount

of alkalis remains the same, the new analysis shows a rock relatively richer in potash as compared with soda.

	I	II	III		I	II	III
SiO_2	44.40	50.96	46.06	ZrO_2	0.03	....	....
Al_2O_3	19.95	19.67	10.01	P_2O_5	0.37	....	0.21
Fe_2O_3	5.15	7.76	3.17	SO_3	0.06	trace	0.05
FeO	2.77	.....	5.61	Cl	trace	0.25	0.03
MgO	1.75	0.36	14.74	MnO	0.08	trace	trace
CaO	8.49	4.38	10.55	BaO	0.01	....	0.32
Na_2O	6.50	7.96	1.31	SrO	....	....	0.20
K_2O	8.14	6.77	5.14				
H_2O (110°+)	1.17	1.38	1.44		100.76	100.01	99.57
H_2O (110°−)	0.24	.....	.....	Less O = Cl	.....	0.06	0.01
CO_2	0.12	.....	.....				
TiO_2	1.53	0.52	0.73		.....	99.95	99.56

I. Arkite, Magnet Cove. Washington, analyst. Sp. gr., 2.770 at 26° C.

II. Arkite, Magnet Cove. Noyes, analyst. WILLIAMS, *op. cit.*, p. 276.

III. Missourite, head of Shonkin Creek, Highwood Mountains, Montana. Hurlbut, analyst. WEED and PIRSSON, *Am. Jour. Sci.*, Vol. II, p. 321, 1896.

The discrepancy between the two analyses of the leucite rock cannot be explained by the supposition that the specimen analyzed by Noyes carried a larger proportion of pseudo-leucite, since, although the other constituents work out well on this basis, the amount of K_2O in II is not intermediate between that in I and in Williams' analysis of a pseudo-leucite crystal. It seems to be the case that Noyes' specimen represents a slightly different phase, possibly richer in aegirite, but poorer in diopside and garnet. From my own observations in the field and the specimens collected, I conclude that the specimen of I represents the normal rock more closely than that of II.

It may be remarked that this supposition is borne out by the fact that analysis I is, in a general way, intermediate between that of the covite and that of the ijolite, given later, while Noyes' is not. This is to be expected in view of the observation noted in my former paper (p. 395), that "while the relations of the 'fine grained' (shonkinitic) syenite to the leucite-porphyry are uncertain, the former lies apparently outside or above the latter."

In the absence of discrimination between the two iron oxides

in II, it is impossible to make a satisfactory calculation of Noyes' analysis, but No. I works out thus, the result being only an approximation, owing to the composition of the rock. In IIIa is given that of the missourite, as calculated by Pirsson.

	Ia		IIIa
Orthoclase	3.9	Leucite	16
Leucite	36.9	Analcite	4
Nephelite	25.5	Zeolites	4
Aegirite	8.4	Augite	50
Diopside	10.8	Olivine	15
Garnet	14.5	Biotite	6
		Iron ore	5
	100.0		100

It is evident from this table that while both rocks are alike in being composed essentially of leucite, with subordinate nephelite (or zeolites), and dark minerals, yet that they differ radically from each other, just as did the covite and shonkinite. The Magnet Cove rock is distinctly leucocratic, carrying about 66 per cent. of light minerals, while the missourite is as decidedly melanocratic, carrying only 24 per cent. of these.

It is obvious from the mineralogical composition, as well as from the analysis, that the name "syenite" which has been applied to this rock is not justified, if this term is to retain any precision of meaning except that of indicating the absence of quartz and an alkaline character. Since this is so, and since the rock represents a most interesting and quite distinct type, it certainly should have a distinct appellation of its own.

It would seem peculiarly appropriate to honor the memory of its first describer, J. F. Williams, by calling it Williamsite. But since this name has been already preëmpted by Shepard for a variety of serpentine, and as it would be a solitary exception among rock names, it will be best not to do so. I propose, therefore, the name of "arkite" (from the usual abbreviation of the state name Arkansas), the essential features being a holocrystalline, porphyritic, leucocratic combination of leucite (or pseudo-leucite) and nephelite, with pyroxene and garnet.

Ijolite.—The analysis of this type, from below Dr. Thornton's, has been already published,[1] but is here repeated, with the addition of several constituents which have been determined since. In II is given the analysis of a typical ijolite from Iiwaara, in Finland. The two do not differ materially, except that I is higher in CaO and correspondingly lower in Na_2O.

	I	II		I	II
SiO_2	41.75	43.70	CO_2	none	....
Al_2O_3	17.04	19.77	TiO_2	0.58	0.89
Fe_2O_3	6.35	3.35	ZrO_2	0.05	....
FeO	3.41	3.94	P_2O_5	1.09	1.34
MgO	4.71	3.94	S	none	....
CaO	14.57	10.30	MnO	trace	trace
Na_2O	6.17	9.78	BaO	none	....
K_2O	3.98	2.87			
$H_2O(110°+)$	0.62	0.89		100.60	100.30
$H_2O(110°-)$	0.28				

I. Ijolite, Magnet Cove. Washington, analyst. *Bull. Geol. Soc. Am.*, Vol. XI, p. 399, 1900. Sp. Gr. 3084—26°C.

II. Ijolite, Iiwaara, Finland. Sahlbom, analyst. V. HACKMAN, *Bull. Com. Geol. Finl.*, No. 11, p. 17, 1900.

The mineralogical composition of the two is given below, that of IIa being Hackman's calculation. II is almost exactly half nephelite, while I contains rather less than half of this mineral, but both may reasonably be called mesocratic. Hackman's specimen did not contain any garnet, but this is a very

	Ia	IIa[2]
Nephelite	38.7	55.00
Aegirite	4.6	7.15
Diopside	31.3	33.22
Augite	6.9	.....
Melanite	15.3	.....
Titanite	....	2.16
Apatite	3.0	3.17
	100.0	100.70

[1] H. S. WASHINGTON, *op. cit.*, p. 399.

[2] There is a clerical error in Hackman's results, as he gives the nephelite as 51.02, the sum as 100.50.

variable constituent in the Finland ijolites. Hackman (*op. cit.*, p. 4) notes the identity between the Magnet Cove rock and the Finland and Alnö ijolites.

Biotite-ijolite.—An analysis was also made of this rock, the specimen coming from near the Baptist church, and the results are given in I. My specimen was, unfortunately far from fresh, so that the figures are of little value. Williams' analysis (II) of the same type, undoubtedly made on fresher material, is to be preferred. The chief feature of interest in I is the (for this oxide) large amount of ZrO_2, which may be correlated with the neighboring "eudialyte-syenite pegmatite" described by Williams.

	I	II		I	II
SiO_2	38.11	38.93	SO_3	none	....
Al_2O_3	20.84	15.41	Cl	....	0.02
Fe_2O_3	5.67	5.10	S	0.14	0.89[1]
FeO	1.46	4.24	MnO	0.14	trace
MgO	3.80	5 57	BaO	trace	....
CaO	14.44	16.49	SrO	....	trace
Na_2O	6.65	5.27	Li_2O	....	trace
K_2O	2.12	1.78			
$H_2O(110°+)$	4.51	5.20		100.60	100.87[2]
$H_2O(110°-)$	0.57		Less O	0.04	
CO_2	0.65	....			
TiO_2	0.48	1.62		100.56	
ZrO_2	0.18	....	Sp. Gr.	2.679—26° C.	
P_2O_5	0.84	0.35			

The composition of the rock is such that any calculation of the mineralogical composition must be rather arbitrary and unsatisfactory, but the following (IIa) represents roughly and

	IIa.
Orthoclase	4.8
Nephelite	24.1
Biotite	6.2
Diopside	30.6
Melanite	23.0
Schorlomite	6.7
Magnetite	3.6
Apatite	1.0
	100.0

[1] FeS_2. [2] Williams gives 100.57.

approximately that of Williams' specimen. It is probable that my specimen was rather richer in nephelite and poorer in dark minerals than Williams'. The composition is much the same in a general way as that of the ijolite, only that it is melanocratic, rather than mesocratic.

Jacupirangite.—A new analysis was made of the dark, coarse-grained rock, composed largely of augite, which occurs as a small mass northeast of the main area, on Cove Creek. This was deemed to be advisable since the analysis of Williams showed more CaO, or less MgO and FeO, than was necessary to form augite or any other mineral present. The analysis of Williams is given in I, and my results in II, with two other analyses for comparison.

No.	I	II	III	IV
SiO_2	36.51	38.39	38.38	45.05
Al_2O_3	8.22	7.05	6.15	6.50
Fe_2O_3	8.29	9.07	11.70	3.83
FeO	3.31	6.17	8.14	7.69
MgO	8.19	11.58	11.47	12.07
CaO	18.85	19.01	18.60	18.82
Na_2O	2.10	0.74	0.78	0.94
K_2O	1.08	0.75	0.13	0.78
H_2O 110°+	1.40	0.33	0.54	2.40
H_2O 110°−	....	0.14	0.18	
CO_2	....	0.32	none	....
TiO_2	3.11	4.54	4.32	2.65
ZrO_2	....	none	....	....
X	....	0.24	....	....
P_2O_5	....	0.82	0.17	0 15
Cl	0.03[1]	....	....	....
S	6.03	0.42	....	....
MnO	trace	0.32	0.16	....
BaO	....	trace	....	....
SrO	trace	....	....	....
	99.22	99.89	100.72	100.88

Sp. gr., 3.407—26° C.

I. Jacupirangite, Magnet Cove. J. F. Williams, analyst. *Op. cit.*, p. 227.

II. Jacupirangite, Magnet Cove. H. S. Washington, analyst.

III. Jacupirangite, Jacupiranga, Sao Paolo, Brazil. H. S. Washington, analyst.

IV. Pyroxenite, Brandberget, Gran, Norway. L. Schmelck, analyst. W. C. BRÖGGER *Q. J. G. S.*, Vol. L, p. 31, 1894.

[1] FeS_2.

While I and II are alike in a general way, yet there are marked differences in SiO_2, FeO, MgO and S. The specimen analyzed by Williams carries considerable pyrite, while mine only showed a few specks of it. The differences in the other constituents named may be attributed to alteration, especially in view of Williams' statement that the specimen analyzed by him was not fresh.[1] Analysis II calculates out readily as follows:

	IIa
Nephelite	4
Diopside	64
Augite	15
Biotite	5
Magnetite	8.7
Pyrite	0.7
Calcite	0.6
	100.0

In my former paper this pyroxenite was referred somewhat doubtfully to the jacupirangite of Derby. Through the kindness of this gentleman, to whom I would express here my deep acknowledgments, I have lately received numerous specimens of the Brazilian types. A comparison of these with the Magnet Cove specimens makes it evident that the two occurrences differ chiefly in size of grain, the Arkansas rock being very coarse, while those from Brazil are much finer grained. In all other essential respects the two are closely alike.

From the microscopical examination of the specimens which Professor Derby sent me, it is evident that the "Jacupirangites" of Brazil vary from rocks rich in nephelite, and which are true ijolites, closely analogous to those of Magnet Cove and Finland, through rocks composed predominantly of pyroxene, with small and varying amounts of magnetite and nephelite, to types extremely rich in magnetite and with no nephelite or only traces of this mineral. Accepting then the name of Jacupirangite for the medium type, the application of this name to the Magnet Cove rock is abundantly justified, since the only difference is the comparatively unimportant one of size of grain, both being holocrystalline.

[1] WILLIAMS, *op. cit.*, p. 227.

That this identity of the two, based on mineralogical grounds, is correct, is substantiated by a chemical analysis of one of Derby's specimens made by myself. For this purpose an apparently medium specimen was chosen, composed largely of a violet-brown augite, with some magnetite (more than in the Arkansas rock) and only a little nephelite (less than in the other). No biotite was present, and only traces of apatite. This analysis, given in III of the table, is most remarkably close to that of the Magnet Cove jacupirangite in all respects, except the iron oxides. Indeed the figures for silica, magnesia, lime, soda, water, titanic acid and manganese are close enough to belong to duplicate analyses of the same specimen, and those for alumina and potash do not differ greatly. The higher iron oxides are of course connected with the more abundant magnetite, but, apart from this, the mineralogical composition is closely similar.

The closest known analogue of these rocks is probably the pyroxenite of Brandberget, an analysis of which is given in IV above. The only noteworthy differences are in SiO_2 and Fe_2O_3. That of the former apparently conditioned the formation of nephelite in the Magnet Cove and Brazil rocks and plagioclase at Brandberget, while the higher ferric oxide of II and III is to be connected partly with the more abundant magnetite in the former.

HENRY S. WASHINGTON.

[*To be continued.*]

THE PRE-TERRESTRIAL HISTORY OF METEORITES.

THE completion of the studies for students relating to the composition and structure of meteorites, which have recently been published in this JOURNAL, furnishes an opportunity for me to record certain deductions which seem to me warranted by the facts there presented, but which, being largely theoretical, had best be stated as the expression of individual opinion.

That theories of the origin and cosmic history of meteorites have been propounded before, and that these have varied widely in character, the present writer is well aware. These theories may be mentioned at the outset, together with the names of those who have given them special support, without, however, entering into any discussion of the merits of each.

Meteorites have been declared to be (1) terrestrial matter discharged into space by the volcanoes of the earth and returned to it again (Sir Robert Ball); (2) matter discharged from the volcanoes of the moon (La Place, J. Lawrence Smith); (3) matter ejected from the sun (Sorby); (4) portions of shattered stars (Meunier); (5) portions of a shattered planet (Boisse); (6) portions of comets (Newton); (7) clouds of gas or dust cemented and solidified by the action of the earth's atmosphere (Brezina).

All of these hypotheses have been urged by men of eminence, each urging strong reasons for his views. These reasons can be learned by study of the original authorities, and the discussion of them in the present article is not a part of my purpose. I shall endeavor here simply to present my own views and my reasons for the same.

The study of meteorites has shown that:

1. The majority of iron meteorites are octahedral.

2. The majority of stone meteorites are chondritic, and contain considerable glass.

3. Between iron and stone meteorites there is every gradation—they are formed of the same sort of matter.

The above statements would probably not be questioned by any authorities of the present day. The following, however, might not be agreed to by all:

4. The substance of meteorites was in a solid state before the fall of these bodies to the earth.

5. The structure of the majority of meteorites shows that their substance has cooled from a liquid or semi-liquid condition to that of a solid.

6. The structure of the majority of iron meteorites shows that the change from a liquid or semi-liquid to a solid state has taken place slowly.

7. The structure of the majority of stone meteorites shows that the change from a liquid or semi-liquid to the solid state has taken place rapidly.

The four latter statements may then be briefly discussed, and important known objections to them stated.

Concerning statement 4: It was suggested by writers in the early part of the last century that meteorites were concretions formed in our own atmosphere. Brezina inclines to accept this view with the modification that the substance of meteorites was extra-terrestrial, but that it arrived at the earth in the shape of gas or dust and was cemented or solidified by the earth's atmosphere. To my own mind, the slickensided surfaces and veins exhibited by many meteorites afford sufficient contradiction of such a view, and compel the conclusion that the matter in which such structures occur had existed in a solid state for a considerable length of time before it reached the earth.

Concerning statement 5: Several writers, but especially Daubree,[1] have expressed the conviction that the substance of meteorites gives evidence of having passed directly from a gaseous or vaporous state to that of a solid. The opinion seems to be based chiefly on Meunier's synthetic experiments, in which he succeeded in reproducing mineral aggregations having the composition of meteorites and somewhat resembling them in structure, by the inter-action of vapors.[2] But, as pointed out by Cohen,[3] the absence of gas and vapor pores in meteorites

[1] "Observations sur les conditions qui paraissent avoir preside a la formation des meteorites," *Comptes Rendus*, 1893, CXVI, pp. 345–7.

[2] *Encyclopedie Chimique*, Tome II, "Meteorites," chap. v.

[3] *Meteoriten-kunde*, Heft I, p. 327.

argues against such an origin of their substance, and further, Fouqué and Lévy produced by cooling from fusion, mineral aggregates as closely resembling meteorites as those made by Meunier from vapors. Again, the crystalline structure of the minerals of meteorites perfectly resembles that of terrestrial minerals known to be produced by cooling from fusion.

Concerning statement 6: That the complete crystalline structure possessed by the great majority of iron meteorites indicates a lapse of time sufficient for a slow, uniform arrangement of the molecules of their mass, in other words a slow cooling, has rarely been doubted. Such a conclusion certainly accords with all terrestrial experience and observation. It has been suggested by Cohen,[1] however, that the crystalline structure expressed in iron meteorites by the Widmanstätten figures may be really a sort of skeleton growth, similar to that seen when needles of ice form over the surface of rapidly cooling water, and that hence the Widmanstätten figures may indicate a rapid crystallization. It is unfortunate that no attempt to reproduce Widmanstätten figures artificially in iron has ever yet succeeded, for if this could be done valuable evidence for judgment on this point could be secured.

Taking the evidence as it stands, however, and especially taking into consideration iron meteorites like that of La Caille, whose structural features show a complete parallelism throughout a large entire mass, the indications seem to me to point strongly to slow crystallization. Certainly analogies between the formation of crystals in iron and in water should be drawn with hesitation. Iron is far more viscous than water and movement in it would take place slowly. Further, the crystalline plates of meteoritic iron differ in composition, showing that time must have elapsed for separation of ingredients as has not taken place in the ice formed upon water.

Concerning statement 7: This opinion is based chiefly on the large quantity of glass found in most of the chondritic meteorites, which, it is to be noted, make up by far the larger

[1] *Meteoriten-kunde*, Heft I, p. 326.

quantity of known stony meteoritic matter. Glass is known to indicate rapid cooling. Further, the character of the chondri themselves is such as to lead many students of the subject, notably Brezina and Wadsworth, to believe that they are the result of rapid and arrested crystallization. The fact that chrysolite, the least fusible and therefore the earliest cooling mineral, forms the most chondri, lends support to this view. It must be confessed that the real origin of chondri is as yet very obscure and the theory above suggested is far from accounting for many of their peculiarities. Yet the facts above noted seem to me to argue more strongly in favor of a rapid cooling of the substance found in such meteorites than a slow one.

If the arguments in favor of the above statements seem sustained, then the conclusion to which they appear to me to point is the following: *Meteorites are portions of a disrupted mass of cosmic matter which had a spheroidal form, increased in density toward the center, and cooled from a liquid or semi-liquid to a solid state before disruption.*

The application of this hypothesis to the subject in hand may perhaps best be traced by applying it in a reverse order. Given a defined quantity of liquid or semi-liquid. It will take the form of a spheroid, since this is the only form known in which a liquid mass would maintain itself in space. Its materials would arrange themselves according to density. The iron, for example, would sink to the center, and the slag-like silicates rise to the surface, as they may daily be seen to do in a blast furnace, or as a centrifugal separator assorts substances according to density. The exterior of the sphere owing to contact with the cold of space would be cooled with comparative suddenness, giving the minerals of the surface a glassy, brittle character. The protected interior would cool more slowly, giving the molecules of the metallic center an opportunity to arrange themselves in an orderly, crystalline fashion. In time, however, the globe becomes solidified from center to circumference. During the process of solidification, and later, many processes of disruption and adjustment go on as the

result of strains of various kinds, record of which is to be found in the structure of meteorites. Fissures will be formed, into some of which pasty metallic matter will be forced from below, and which will, in its passage upward, enclose angular fragments of the siliceous crust. Other fissures occurring only in the siliceous portion of the globe will give rise to the formation of quantities of angular fragments, which will be cemented together again by pressure to form breccias. Such fissures would be comparatively large, and affect a considerable area of the globe. Other minor fissures would form in ramifying networks, which would be filled by adjacent substance penetrating in a more or less liquid form. Differential movements of solid portions, without the existence of fissures, would produce slickensided surfaces. Finally, the progressive disruption of the body occurs. To produce this, two or three forces may be appealed to. In the first place, there is the familiar fissuring from shrinking and contraction as the body passes from the liquid to the solid state. It is perfectly evident that a certain amount of this is taking place upon the earth.[1] Meunier suggests further, that in the moon we can see this process extended as much farther as the moon is more fully cooled than the earth, and he regards the well-known bright streaks of the moon as enormous fissures (*rainures*) showing a progressive disruption of its mass.[2] While few probably at the present day would accept this interpretation of the bright streaks of the moon, there are numerous other indications that the moon is considerably fissured. Meunier also points to the asteroids as an illustration of a dismembered heavenly body.

In the second place, strains corresponding to the tidal strains of the earth would produce a constant disruptive effect; and, in the third place, the recent investigation of Professor Chamberlin,[3] has shown how the fragmentation of a small body may take place by near approach to a large one.

Once the body is broken up, its fragments may be drawn out

[1] See CHAMBERLIN, "On a Possible Function," etc., JOUR. GEOL., Vol. IX, No. 5.

[2] *Cours de Géologie Comparée*, pp. 258 *et seq.* [3] *Op. cit.*

into the form of a somewhat attenuated swarm or cluster. The possibility of the subsequent capture of single portions of such a cluster by the earth can hardly be denied. The character of the portion captured, in respect to its structure, density, and composition, then, will depend on the position it occupied in the globe of which it formed a part.

That meteorites exist in such swarms in space seems very probable from a recent investigation of Högbom.[1] Plotting the known meteorite falls according to the days of the year, he has discovered undoubted and significant groupings. Thus of the nine known howardites, three fell during the first days of August, and three during the first half of December. The probabilities are stated to be several thousand to one against such an occurrence being a mere coincidence. Again, of the three known eukrites two fell June 13–15. The chances are said to be ninety to one that these had a common origin. There are numerous other groups brought out on the chart so made, which seem to point to the existence in space of meteorite clusters met on the same date by the earth in its annual revolution. The probabilities seem sufficiently in favor of the existence of such clusters to warrant placing some reliance in the constitution indicated for them. Thus with the group of August howardites previously mentioned are associated one siderite and three chondrites; with the December howardites, one siderite, one bustite, one chladnite, and a number of chondrites. The constitution indicated for these swarms resembles therefore, to a remarkable degree, that called for by the hypothesis here advocated, especially when it is remembered how exceedingly fragmentary must be evidence based on the few meteorites seen to fall. A similar constitution has been also exhibited at times in the substance of a single meteoric shower. A notable case is that of Estherville, which contained all gradations, from iron to stone meteorites.

Two or three other points of evidence may be noted as tending to show that, in such a globe as that assumed, the substances

[1] *Bull. Geol. Inst. of the University of Upsala*, Vol. V., Part 1.

were arranged in order of their densities and that it had at some time a hot interior and cold exterior.

The first is drawn from our knowledge of the crystallography of iron. According to modern metallographists, iron occurs in three allotropic modifications known as alpha, beta, and gamma irons. When heated to a temperature not higher than 700° C., iron remains in what is known as the alpha state; from 700 to 860° C. it assumes the beta state, and from 860° C. to the melting point, the gamma state. In cooling, from the melting point, for instance, the iron does not necessarily return through these modifications, but remains in the state which it assumed at the highest temperature.[1] Now gamma iron crystallizes in octahedrons, while alpha and beta iron crystallize in cubes. The majority of meteoritic iron is plainly octahedral in structure. It is hard to escape the conclusion, therefore, that it has been heated to a temperature at least as high as 860° C., and, further, that the cubic irons, some of which occur among meteorites, have been subjected to a somewhat lower degree of heat. The latter, it is true, must be cooled and reheated to a somewhat lower temperature than at first to have their structure accounted for on this theory. But this could quite reasonably occur, and their relative quantity is so small as to make them of minor importance.

A second corroborative fact is that the carbonaceous meteorites are of exceptionally low specific gravity. Now the carbonaceous meteorites are those which contain hydrocarbons which could not exist under any high degree of heat. Such meteorites could not have experienced any sensible heating subsequent at least to the formation of these hydrocarbons. But the low density of these meteorites would place them, according to the hypothesis, on the outer surface of the spheroid, where, after the first solidification from cooling, little further heating would be encountered.

A third corroborative fact is found in the existence of diamonds in the iron meteorite of Cañon Diablo, a meteorite

[1] F. OSMOND, *The Metallographist*, July, 1900.

which exists in quantity amounting to several tons. Such diamonds have been produced by Moissan by heating to a high temperature iron saturated with carbon and allowing it to cool under pressure. This is exactly the process through which the substance of an iron meteorite would pass if formed according to the above hypothesis. The other meteorite known to contain diamonds, Nowo-Urej, is also one which would have formed not far from the metallic center of such a globe, as it contains large metallic veins and by some is classed among the iron-stone meteorites.

The hypothesis outlined above may ask the special attention of the geologist, on account of the suggestions it may offer regarding the history of the earth. If it be true that meteorites are fragments of a broken-up globe, it is not unlikely that they show to us, to some extent, the constitution of our own globe. Uniformity of cosmic matter has been indicated by all studies of meteorites, as well as by all spectroscopic inquiries into the chemistry of space. Uniformity of cosmic history seems therefore probable also.

I have shown in the studies previously referred to that meteorites chiefly differ in composition from the crustal terrestrial rocks with which we are familiar in having an excess of iron, nickel, and magnesium, and in being practically without free silica, oxygen, and water. Assuming that the earth, however, has passed through a history like that of the globe above hypothesized, the absence of iron, nickel, and magnesium[1] from its crust is explained by the conclusion that they have been carried within its interior by their density. They are therefore removed from our observation, except as occasional outflows such as that known in Greenland bring them to view. It is well known that the density of the earth as a whole requires that its interior contain matter of higher specific gravity than that with which we are familiar upon its crust, and it has often been suggested that

[1] Magnesium is here referred to not as the element, which is relatively light, but as the essential constituent of chrysolite, which is of high specific gravity and forms some of the heaviest terrestrial eruptive rocks.

this matter may be iron and other metals. The alternative supposition is that the matter of the interior may be like that of the crust but has become denser through condensation and pressure.

The free silica of the earth's crust is readily accounted for if we remember that the rocks of the earth's crust have been *worked over*, while in meteorites they are seen in their primitive condition. When silicates are exposed to the action of carbonic acid for any length of time the bases change to carbonates and silica is set free.[1] It seems reasonable to suppose that the vast amount of calcium and magnesium now held as limestone was originally in the form of silicates. If the carbonic acid of the limestones should be withdrawn to the atmosphere, and their bases combine with the excess of silica of the crust, rocks as basic as those of meteorites would probably be formed.

Similarly, the lack of oxygen in meteorites may be only relative, and because much of the matter of which they are composed was in the interior, deep-seated and protected from gaseous action. The superficial, lighter siliceous portions of meteorites are found to be oxidized. It is reasonable to believe the earth's substance is not oxidized except for its superficial crust. It may be urged in support of the view that oxygen could not have been present where meteorites were formed that little or no oxygen is found among the free gases obtained from meteorites. But rocks do not seem to have the power of absorbing and holding oxygen as they do other gases. Terrestrial rocks do not contain it, although they hold hydrogen, carbon dioxide, and carbon monoxide in large quantities.[2] Yet there is no lack of oxygen in the earth's atmosphere.

The absence of water from meteorites is an important gap in the parallelism of constitution of meteorites with that of the earth. In the gases hydrogen and oxygen, which it has been shown meteorites possess, a cosmic body has the elements necessary for the formation of water. Conditions of nascence, or possibly of electricity, might exist in a body the size of the

[1] This fact is more fully stated by SIR JOHN MURRAY, *Proc. Roy. Soc. of Edinburgh, 1890–1*, p. 229.

[2] See *Studies*, JOUR. GEOL., Vol. IX, p. 402.

earth, which would lead to the formation of water from these gases, which might not prevail upon a body of smaller size. The chief reason, however, for the absence of water from meteorites seems to be the fact that the size of the meteorite spheroid was probably not sufficient to enable it to hold a quantity of the free gases competent to the formation of water or even to retain water vapor if it was once formed. The spheroid was probably as destitute of an atmosphere as the moon.

I am well aware that an origin of meteorites from a shattered globe has been suggested before. Boisse was perhaps the first to do this,[1] but the idea was especially elaborated by Meunier,[2] who reconstructed from the various types of meteorites a hypothetical globe in which these types were arranged largely in accordance with their density. But the hypotheses of these authors were based purely on considerations of density, it being arbitrarily assumed that in a cosmic body substances *would* arrange themselves according to density.

It was when a study of the structural characters of meteorites showed me that the substances *had* apparently arranged themselves in the order of their density, and exhibited corresponding differences of structure, that I was led to form the above hypothesis; and it is perhaps worth remarking that I reached this conclusion before I had seen Meunier's papers on the subject.

It is not likely that the globes or spheroids, such as have been here hypothesized, were of large size. In the solar system, for example, there is no indication that the total disruption of a body anything like in size to a planet has ever taken place. Such an occurrence would produce effects more catastrophic in their nature than could be referred to matter so small in relative quantity as that which has within human experience reached the earth in the form of meteorites. Such globes would, perhaps, in their entirety, never come within human observation. But that there exists in space a vast quantity of fragmental matter beside that visible to us as stars, nebulæ, and the bodies of the solar system, there can be little doubt. OLIVER C. FARRINGTON.

[1] *Memoires de la Société des lettres, sciences et arts de l'Aveyron*, Vol. VII, p. 168.

[2] *Cours de Géologie Comparée.*

EDITORIAL

WITH this number we present to the readers of the JOURNAL two able articles on geologic classification and nomenclature. It is expected that these will be followed by others representing different points of view. In the opening numbers of the next volume we hope to offer a series of very carefully matured articles on the classification and nomenclature of minerals and rocks, by some of our foremost petrographers. It is hoped that these discussions will receive the thoughtful consideration of progressive geologists and petrographers. The importance of revising our present systems of classification and nomenclature, if systems they may be called, is equaled only by the importance of thorough preliminary scrutiny of the proposed substitutes, lest we impose on ourselves new systems scarcely less infelicitous than the old. A critical and deliberate circumspection, attended by full discussion, may well be followed by the adoption of the improved systems by those who have become convinced of their merits, if full liberty to follow the old practice is unreservedly accorded to the unconvinced and to the constitutionally conservative. It is doubtful whether we should try to force new systems into usage by legislative processes, but concerted adoption by those who have the courage of their convictions will go far towards securing the desired end.

T. C. C.

Reviews.

Zinc and Lead Region of North Arkansas. By John C. Branner (Arkansas Geological Survey, Annual Report 1892, 396 pp., Little Rock, 1901.)

The lead and zinc deposits of the Ozark region have received attention from the geological surveys of Arkansas, Missouri, Kansas, and the federal government. The United States Geological Survey and the University Geological Survey of Kansas will shortly have out reports on the subject. Missouri, through her geological survey, has already published an exhaustive account of the deposits in two large volumes, by Mr. Arthur Winslow. After delays of nearly ten years, Arkansas has at last seen fit to make appropriations for the publication of the report on the zinc and lead deposits of the north part of the state. It is by the former state geologist, Dr. J. C. Branner.

The publication of Dr. Branner's report has long been looked forward to by all interested in the subject of lead and zinc. In many respects it is the most welcome contribution to our knowledge of the geology of the Ozark region that has yet been made.

Preliminary to the consideration of the ores is a short description of the surface relief of the region, illustrated by an excellent photographic reproduction of Branner's Relief Model of Arkansas. The zinc and lead deposits described are located chiefly north of the Arkansas river. "The region here included under the name of Ozark plateau embraces nearly all of that part of the Ozark mountains within the state of Arkansas. It includes almost the entire region between the Arkansas river and the Missouri line, and between the St. Louis, Iron Mountain & Southern railway and the Indian Territory line. The Ozark region in Arkansas is made up of three plateaus that rise like ragged-edged steps one above another, each with a few outliers standing out upon the next step below."

In order of their importance, the zinc ores of northern Arkansas are sphalerite, smithsonite and calamine, besides several other minerals of zinc which do not occur in sufficient quantities to entitle them to be looked upon as ores.

The zinc ores are regarded as having been deposited by underground waters. Emphasis is laid on their accumulation along synclinal troughs and water-way breccias. "The details of the theory of the accumulation of the Arkansas ores along synclines and other water-ways were first suggested by field observations made in this region in 1889, and the whole theory has been much strengthened by subsequent work."

According to their genetic relations there are three kinds of sulphide ores: (*a*) the bedded deposits, which are contemporaneous with the rocks in which they occur; (*b*) the veins and other fracture deposits in which the ores are of later age than the accompanying beds, and (*c*) the breccia deposits not formed on fractures, but likewise of later age than the accompanying beds. In addition to the sulphide ores there are carbonate and silicate ores, derived by alteration from the sulphides and forming genetically a fourth class.

Regarding the origin of the bedded deposits, it is stated that they "have originated for the most part where we now find them." The cherts are made of silica of organic origin, that is, they were deposited over the sea bottom as silicious skeletons of diatoms or other microscopic remains of plants or animals. The zinc came from the adjacent land areas of the period in which these beds were laid down. Upon entering the sea the zinc-bearing waters had their zinc contents precipitated in the form of sphalerite or zinc sulphide by the organic matter that contributed the silica of the chert beds. The zinc crystallized out while these silicious sediments were yet soft and yielding. In time the sediments hardened and formed the firm, flinty rocks and pressed closely about the zinc blende crystals.

"The crystals of zinc blende, however, were not originally as large as we now find them in the disseminated ores, even where these crystals are no larger than a pin head. They were at first even microscopic, but, as Ostwald has pointed out, there is a tendency in such cases for the small crystals to pass into solution and to recrystallize upon the larger ones which grew at the expense of the small ones. In the bedded deposits this took place before the enclosing sediments were hardened."

The vein deposits are those occupying the spaces left by fractures in the strata. The ores are confined to the fractured zone and to its immediate walls. When the ore is found in the walls it seldom penetrates them to any considerable depth, but is confined to small

fractures that seem to be parts of the great fissures. In appearance the fissure ores are not different from the bedded deposits. But they are stated to have a very different origin. The ores of this class have all been brought into their present position by solution, probably from the Ordovician bedded deposits.

The question of the origin of the breccia ores "has been one of the most puzzling problems encountered in the zinc regions. The only theory for these formations that seems tenable is that of the apparently irregular masses of breccia, that is, the breccias not upon fault and such like fractures, have been formed along ancient underground water-courses."

One of the most suggestive points brought out in this consideration of the zinc ores is the relation of synclines to the presence of ores. Dr. Branner says: "If the hypothetical history here assigned the north Arkansas zinc ores is thus far correct, we are forced to conclude that the geologic structure of the region is of the utmost importance in the determination of the present distribution of the ores. In an elevated region of approximately horizontal or very gently folded sediments, the waters falling upon the ground and soaking into the earth tend to seek the bottoms of the synclinal troughs. The process of ore accumulation in such a region would therefore tend to carry the ores into the synclines. The rocks of the zinc region, although not far from horizontal, are gently folded. Wherever folds have been exposed in the zinc mines the bottoms and sides of these folds have been found richer in zinc than the adjacent portions of the same beds. This is a rule to which I know but few exceptions. The inference seems to be warranted that the synclinal troughs should be located and examined for the richer zinc accumulations."

Of exceptional interest at this time are the notes on the faults of north Arkansas. For the first time in the consideration of the zinc region something tangible regarding these structures and their character is made available. The throw of the faults, though never very great, is sometimes four hundred feet or more. The character of the folds found in the vicinity of the faults is shown by numerous figures.

The illustrations are unusually good.

C. R. KEYES.

Texas Petroleum. By WILLIAM BATTLE PHILLIPS, Ph.D., Director. The University of Texas Mineral Survey Bulletin No 1; 102 pp., plates, maps. Austin, July, 1901.

THE University of Texas Mineral Survey, organized in May, 1901, with Dr. William B. Phillips of the university as director, establishes a new record for expeditious work in official geologic investigation by the timely appearance of this volume on a subject which is attracting much attention within the state and without.

An historical account of the development of the Texas oil fields is followed by a chapter on the nature and origin of petroleum, and other chapters on the oil and gas-bearing formations and the utilization of Texas oils.

The Paleozoic formations are not known to hold oil or gas in commercial quantities. The Cretaceous formation, more specifically the Corsicana field, has furnished practically all of the oil which has been produced until the current year. This field has a well-defined extent of from two to three miles in width by six and one-half miles in length in a northeasterly direction. The oil is reached at a depth of 1,050 feet in a soft, gray, foraminiferal shale. In July, 1901, there were 603 producing wells, with an average daily output of about 3,000 barrels of oil worth 70 cents per barrel. The production of oil in Texas for 1899 was 669,013 barrels, while that for 1900 was 836,039 barrels, almost all coming from this field. The Corsicana refinery has a capacity of 1,500 barrels of crude oil daily. Half the output consists of gasoline and kerosene, the residuum being marketed as fuel.

In the Tertiary, the Nacogdoches field was the first to be discovered, dating from 1867. The oil is found in Eocene strata at depths of 70 to 150 feet, and is a heavy lubricating oil with a high boiling point and non-gumming qualities. No oil has been produced in this region since the early part of 1900.

The Beaumont field has been the center of attraction since January 10, 1901, when the famous Lucas "gusher" was brought in. In July, 1901, there were fourteen producing wells all within an area 1,000 by 2,000 feet on Spindle Top Heights, a low ridge lying about four miles south of Beaumont. The ridge is about one mile wide and two miles long in a northeasterly direction and reaches a maximum elevation of 30 feet above the surrounding prairie. Wells outside the proven area are dry. It is presumed that the ridge marks an anticline, though

the structure is not yet known certainly. Concerning the fabulous production of the gushers, no definite figures can yet be given, but the production is unquestionably large. Pipe lines connect the field with tide water at Sabine Pass and Port Arthur where refineries are in process of construction. In quality the oil is a heavy fuel oil, the price of which, in July, 1901, varied from 20 to 40 cents per barrel.

In connection with the origin of the oil, an investigation was made of the so-called "oil ponds," certain quiet spots in the Gulf near Sabine Pass and popularly supposed to be caused by oil escaping from submarine springs. The areas were found to be over extensive beds of black ooze. The examination of samples of this ooze disclosed the presence of sulphur and of diatoms containing oil globules, but of no free oil except such as manifestly came down from the overflow of the Beaumont wells. Sulphur deposits occur over the Beaumont oil horizon. The possible analogy of the present conditions to the conditions prevailing when the Beaumont oil-bearing formation was deposited is suggested as well as the possible connection of diatoms with the oil production.

The report is well printed and illustrated with a number of photographs of characteristic scenes in the different fields, including several of the "gushers" in action, and is in all respects a worthy inauguration of the new survey.

C. E. S.

Lessons in Physical Geography. By CHARLES R. DRYER. American Book Co.: New York, Cincinnati, and Chicago, 1901.

This text-book of high-school grade covers the field of physical geography from the modern standpoint. It has several characteristics for which it deserves recognition as more than a mere variation of what has already been accomplished in other books. It is, first of all, a very concrete presentation of the physiographic principles which have recently come into prominence. Thirty-four pages are given to three typical river systems, the Mississippi, the Colorado, and the St. Lawrence, and thirteen pages to the drift sheet of North America, beside the general treatment of glaciers. The chapters which are devoted to more general subjects also abound in descriptive examples and pictorial illustrations. In the second place, the book has a large number of illustrations which are new to text-books; many of these are drawn from Indiana and neighboring states and will be welcome

to teachers as showing that the modern science of physiography does not rest on a few classical examples. The book leaves the very wholesome impression that the United States abounds in valuable illustrations which are yet unknown to text-book literature, the bringing forward of which depends largely upon teachers who are working in their vicinity, just as Mr. Dryer has sought out those of his own state. The arrangement of the book is good for those who may wish to follow the author's own order and convenient for those who do not. The suggestions on method, both in the "Realistic Exercises" and in the appendix, are helpful. The teacher is introduced to many of the valuable materials which are now available for this study. A good bibliography is given. The author is plainly in touch with the most recent work in his science. A few statements or suggestions in geology do not take into account some of the recent work. A sentence on p. 48, despite previous cautious statements, implies the belief that isostacy alone may support the earth's broad plateaus. On the same page the wrinkling of the earth's crust is ascribed solely to cooling of the interior. A faulty impression of slate would be left by the mention on p. 32. Under "Causes of Glacial Motion," three theories are mentioned: plastic flow, regelation, and alternate melting and freezing. Processes which in recent studies have become more prominent than these are not mentioned. The too general and perhaps misleading contrast between the "older drift" and the "newer drift" are not due to any lack of information on the author's part, whose familiarity with the complexity of drift problems is shown both in this and other writings. An unfortunate expression on p. 135 would leave the impression that the Great Basin as a whole is actually a *basin* with a rim. The mention of "subordinate basins" serves to emphasize this error. Small shortcomings like those mentioned here are but rare exceptions in this very good text-book. In its characteristic qualities the book not only meets the general demands of good science and good teaching, but is well adapted to the particular needs of the present time.

N. M. F.

Some Notes Regarding Vaerdal; The Great Landslip. Dr. Hans Reusch. *Norges geologiske Undersögelse;* Aarbog for 1900.

This complete and well illustrated note, which Dr. Reusch has summarized in English, recounts a very remarkable landslip. The

level surface into which the river Vaerdal has cut a steep-sided valley is an upland of stratified marine clays, deposited during a submergence of the Norway coast since the Glacial Period. Within these clays was a great mass of "quick clay" not constituting a definite stratum but existing, probably, in more or less definite lenticular masses. A small side stream, the Follo, had cut a short gorge into the quick clays, giving the latter an exit to the main valley. On the night of the 19th of May, 1893, a volume of this semi-fluid clay, estimated at 55 million cubic meters, escaped into the larger valley, inundating it to the extent of eight and one half square kilometers. The collapse occupied one half hour and the advancing front of the mud traveled five or six kilometers in three quarters of an hour. Some of the inhabitants were rescued from the roof of their house after sailing three and a half miles on the river of mud. Over a part of the area the upper layer of clay was firm, and, with the overlying turf, constituted a crust sufficiently strong to remain intact while the quick clay flowed out from beneath. Parts of fields bearing trees were thus dropped vertically downward, leaving the trees standing erect at the lower level. The vertical distance through which the surface fell is not given, but the pictures represent it as many meters and the sides of the pit as quite sheer in many places. The author gives a note, also, on a similar but smaller landslip which occurred on the 16th of August of the same year in the valley of the small stream Graaelven. The finely banded marine clays concerned in this slip are made the basis of a time estimate. Their thickness is taken at fifty meters, and they consist of alternating dark and light layers. On the supposition that one dark layer and an adjacent light layer were deposited in one year, the time consumed in their deposition is estimated at 4,000 years. The proportion of post-glacial time which this represents is not estimated.

N. M. F.

Geological Map of West Virginia. Second edition. I. C. White, State Geologist. Published by West Virginia Geological Survey, Morgantown, W. Va.

The Geological Map of West Virginia, first published in 1899, has recently been revised and new features added. The map shows in separate colors the three great coal formations of West Virginia, viz., the New River or Pocahontas, the lowest; the Allegheny-Kanawha

series in the middle; and the Monongahela or Pittsburg (Connellsville) at the top. Two features not shown on the original map have been added in this edition, viz., the prominent anticlinal lines, and the locations and names of every coal mine in the state shipping coal by rail or river, up to July 15, 1901, the approximate locations of the mines being indicated by numbered black dots, and the corresponding names and numbers printed on the margin of the map by counties. The map shows also oil and gas developments of the state, and should prove of much use to those interested in these subjects. Copies may be purchased (50 cents) from the West Virginia Geological Survey, Box 448, Morgantown, W. Va.

Recent Publications

—American Academy of Arts and Sciences, Proceedings of the. Vol. XXXVI, No. 29, June, 1901.

—Ami, Henry M. Knoydart Formation of Nova Scotia. [Bull. of the Geol. Soc. of America, Vol. XII, pp. 301–312, Pl. XXVI.] Rochester, 1901.

—Atti della Academia Olimpica Di Vicenza. Annate 1899–1900, Vol. XXXII. Vicenza, 1900.

—Barton, George H. Outline of Elementary Lithology. Boston, 1900.

—Branner, John C. The Zinc- and Lead-Ore Deposits of North Arkansas. [A paper read before the American Institute of Mining Engineers, at its Mexican Meeting, November, 1901.] Author's edition, 1901.

—Buckley, Ernest Robertson. The Clays and Clay Industries of Wisconsin. [Bulletin No. VII (Part I), Economic Series No. 4, Wisconsin Geological and Natural History Survey.] Madison, Wis., 1901.

—Calhoun, F. H. H. Early Conceptions Concerning the Earth and Natural Objects. [Reprinted from the Bulletin of the American Bureau of Geography, Vol. II, No. 3, September, 1901.

—Cushing, H. P. Geology of Rand Hill and Vicinity, Clinton County. [Reprinted from the Nineteenth Annual Report of the State Geologist; University of the State of New York: State Museum,] Albany, 1901.

—Dryer, Charles R. Lessons in Physical Geography. American Book Company, New York, Cincinnati, Chicago, 1901.

—Dubois, Eug. Les Causes Probables du Phénoméne Paléoglaciaire Permo-Carboniférien dans les Basses Latitudes. [Extrait des Archives Teyler, Séri II, T. VII, Quatrième partie.] Haarlem, 1901.

—Glangeaud, M. Ph. Monographie du Volcan de Gravenoire Près de Clermont-Ferrand. [Bulletin des Services de la Carte Géologique de la France et des Topographies Souterraines. No. 82, Tome XII, 1900–1901.] Paris, 1901.

—Grant, Ulysses Sherman. Preliminary Report of the Copper-Bearing Rocks of Douglas County, Wisconsin. [Wisconsin Geological and Natural History Survey Bulletin No. 6 (Second Edition); Economic Series No. 3.] Madison, Wis., 1901.

—Hall, C. W. Keewatin Area of Eastern and Central Minnesota. [Bull. of the Geol. Soc. of America, Vol. XII, pp. 343–376, Pls. XXIX–XXXII.] Rochester, August, 1901.

—Keweenawan Area of Eastern Minnesota. [Bull. of the Geol. Soc. of America, Vol. XII, pp. 313–342, Pls. XXVII, XXVIII.] Rochester, August, 1901.

—HÖGBOM, A. G. Eine Meteorstatistische Studie. Hierzu eine Tabelle und Tafel IV. [Reprinted from Bull. of the Geol. Instit. of Upsala, No. 9, Vol. V, Part I, 1900.] Upsala, 1901.

—Kansas Academy of Sciences, Transactions of the. Vol. XVII, 1899–1900. Topeka, 1901.

—LEROY, OSMOND EDGAR. Geology of Rigaud Mountain, Canada. [Bull. of the Geol. Soc. of Am., Vol. XII, pp. 377–394, Pls. 33–34.] Rochester, September, 1901.

—List of the published writings of Elkanah Billings, F. G. S., Paleontologist to the Geological Survey of Canada, 1856–1876. Prepared by B. E. Walker, F. G. S., Toronto, Canada. [Reprinted from the Canadian Record of Science, Vol. VIII, No. 6, for July, 1901. issued 10th August, 1901.]

—MOHR, CHARLES. Plant Life of Alabama. [Reprint of Vol. VI, Contributions from the U. S. National Herbarium, published July 31, 1901, by the U. S. Dept. of Agriculture. Prepared in coöperation with the Geological Survey of Alabama. Eugene Allen Smith, State Geologist.] Alabama Edition, with portrait and biography of the author. Montgomery, Ala., 1901.

—New York Academy of Sciences, Annals of the. Vol. XIV, Part I. Charles Lane Poor, Editor.

—PITTMAN, EDWARD F. The Mineral Resources of New South Wales. Geological Survey of New South Wales; Edward F. Pittman, Government Geologist.

—PROSSER, CHARLES S. The Paleozoic Formation of Allegany County, Maryland. [Reprinted from the Journal of Geology. Vol. IX, No. 5, July–August, 1901.] The University of Chicago Press.

—READE, T. MELLARD. Sand-Blast of the Shore and its Erosive Effect on Wood. [Extracted from the Geological Magazine, N. S., Decade IV, Vol. VIII, pp. 193–194, May, 1901.] Dulau & Co., 37 Soho Square, W., London.

—READE, T. MELLARD, AND PHILIP HOLLAND. The Green Slates of the Lake District, with a Theory of Slate Structure and Slaty Cleavage. [Reprinted from the Proceedings of the Liverpool Geological Society, 1900–1901.] Liverpool, 1901.

—REUSCH, HANS. Norges Geologiske Undersögelse, No. 32. Aarbog for 1900. [With English Summary.] Kristiania, 1901.

—RUSSELL, ISRAEL COOK. Geology and Water Resources of Nez Perces County, Idaho, Parts I and II. [Bulletins No. 53 and 54, Water-Supply and Irrigation Papers of the United States Geological Survey.] Washington, 1901.

—SHIMEK, B. I. Pyramidula Shimekii (Pils.) Shim. II. The Iowa Pteridophyta. [Excerpt from the Bulletin of the Laboratories of Natural History, State University of Iowa. Vol. V, pp. 139–170.] April, 1901.

The Loess of Iowa City and Vicinity. Iowa Pteridophyta (Con.). Addenda to the Flora of Lyon County. [Excerpt from the Bulletin of the Laboratories of Natural History, State University of Iowa. Vol. V, No. 2, pp. 195–216.] May, 1901.

—STOKES, H. N. On Pyrite and Marcasite. [Bulletin of the United States Geological Survey, No. 186: Series E, Chemistry and Physics, 35.] Washington, 1901.

—TURNER, H. W. The Esmeralda Formation, A Fresh-Water Lake Deposit in Nevada. With a Description of the Fossil Plants, by F. H. Knowlton, and of a Fossil Fish, by F. A. Lucas. [Extract from the Twenty-first Annual Report of the United States Geological Survey, 1899–1900, Part II, General Geology, Economic Geology, Alaska.] Washington, 1900.

—United States Department of Agriculture, Division of Soils, Milton Whitney, Chief. Circular No. 8 :Reclamation of Salt Marsh Lands, Thomas H. Means, Assistant.

Bulletin No. 17: Soil Solutions, Their Nature and Functions, and the Classification of Alkali Lands; by Frank K. Cameron, Soil Chemist, Division of Soils (Coöperating with the Division of Chemistry). Washington, 1901.

Bulletin No. 18: Solution Studies of Salts Occurring in Alkali Soils; by Frank K. Cameron, Lyman J. Briggs, and Atherton Seidell. Washington, 1901.

—Washington Academy of Sciences, Proceedings of the.

Papers from the Hopkins Stanford Galapagos Expedition, 1898–1899. II. Entomological Results (2): Diptera; by D. W. Coquillet, Custodian of Diptera, United States National Museum. Vol. III, pp. 371–379, November 7, 1901.

Papers from the Hopkins Stanford Galapagos Expedition, 1898–1899. III. Entomological Results (3): Odonata. [Text Figures 29–34. By Rolla P. Currie, Aid, Division of Insects, United States National Museum. Vol. III, pp. 381–389, November 7, 1901.

Papers from the Hopkins Stanford Galapagos Expedition, 1898–1899. IV. Entomological results (4): Orthoptera. [Text Figures 35–44.] By Jerome McNeill. Vol. III, pp. 487–506, November 7, 1901.

Synonomy of the Fish Skeleton. [Plates LXIII–LXV. Text Figures 45–46.] By Edwin Chapin Starks, Leland Stanford Junior University. Vol. III, pp. 507–539, November 7, 1901.

WEED, W. H., and L. V. PIRSSON. Geology of the Shonkin Sag and Palisade Butte Laccoliths in the Highwood Mountains of Montana. [From the American Journal of Science, Vol. XII, July, 1901.]